UNIVERSITY OF ALBERTA

WEED COMPETITION EFFECTS ON THE GROWTH AND YIELD OF GLYPHOSATE-TOLERANT CANOLA.

BY

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled WEED COMPETITION EFFECTS ON THE GROWTH AND YIELD OF GLYPHOSATE-TOLERANT CANOLA submitted by BRIAN SPENCER SCHILLING in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE IN PLANT SCIENCE.

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This thesis is dedicated to my parents, Bruno and Karen Schilling,
for their love and support.

ABSTRACT

Field and greenhouse experiments were conducted over two years to determine the influence that competition from wild oat (*Avena fatua* L.) and red root pigweed (*Amaranthus retroflexus* L.), the time of weed removal, and the effects of single and multiple applications of glyphosate had on the growth and yield of glyphosate-tolerant canola cultivar 'Quest'®. Field experiments were conducted using pre-plant incorporated (PPI) ethalfluralin and post-emergent glyphosate, applied alone or in sequence to control high or low wild oat or red root pigweed densities in canola. Greenhouse experiments were conducted to determine the effects of wild oat and red root pigweed competition and single and multiple applications of glyphosate on glyphosate-tolerant canola.

Wild oat had a greater effect on canola growth parameters and yield than red root pigweed. Greenhouse experiments showed it was important to remove wild oat early whether moisture stressed or not. Canola growth parameters were affected more at a high than low wild oat density, and greater differences occurred between high and low wild oat density at field capacity (FC) than 1/4 FC. Field experiments showed that the earlier weeds were removed from the crop with glyphosate, the higher the crop yield. A double application of glyphosate applied at an early and late canola stage generally resulted in lower canola yields than single applications, suggesting crop injury. Greenhouse experiments showed that multiple applications of glyphosate decreased canola growth parameters more than single applications.

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Chapter 1

1.1 Introduction

Plant growth is affected by environmental factors which include both resource availability and environmental conditions. Resources include moisture, light, and nutrients, and conditions include temperature and soil pH. When an undesirable species grows with the desired species or crop, the undesired species is considered a weed. Weeds compete with crop plants for resources. Plant competition occurs between two different species (inter-specific competition) and between plants that are of the same species (intra-specific competition) (Harrison et al., 1985; Morishita et al., 1991; O'Donovan and Blackshaw, 1997; O'Donovan et al., 1988; Shrefler et al., 1994; Vleeshouwers et al., 1989). The amount of inter- and intra-specific competition is influenced by environmental factors, weed species, weed density, spatial distribution and duration of growth of both the weed and the crop (Berti et al., 1996; Bleasdale, 1960; Spitters and van den Bergh, 1982), making crop-weed competition interactive and complex. Removing weedy species from the crop, helps the crop to grow by decreasing some of the possible stress that plants may encounter. Stress, both from lack of resources and adverse conditions, prevents plants from achieving the maximum growth that is genetically possible within the growing season (Patterson, 1995).

The competitiveness of the crop, and the weed, and the growing environment, will all influence the amount of crop growth, and at the end of the growing season the amount of yield (Blackshaw et al., 1987; Crook and Renner, 1990; Hall et al., 1992; Tapia et al., 1997). Some crops are capable of withstanding higher weed pressures than other crops or are able to compete more successfully against certain weeds than other crops (Beckett et al., 1988; Patterson and Flint, 1983; Schweizer, 1983). Increased weed pressure and the length of time during which weed interference occurs within a crop, results in increased yield loss due to inter-specific competition (Crook and Renner, 1990; Cudney et al., 1989; Hall et al., 1992; Stahlman and Miller, 1990; Vangessel et al., 1995). It has been reported that soybeans require a six to seven week weed-free period after seeding (Williams and Hayes, 1983) and corn requires at least a three week weed-free period after seeding (Knake and Slife, 1965; Wilson and Westra, 1991), depending on the weeds present, to prevent yield loss. Therefore, it is important to know the time period within which weeds must be controlled to prevent yield loss (Zimdahl, 1988).

When controlling weeds, it is important to know thresholds. Period threshold can mean the time period that weeds can compete with the crop before there is any yield loss (Dawson, 1986). Weed competition, before yield loss occurs, can range from two to eight weeks after crop emergence (Coble et al., 1981). Also, period threshold can mean the time period in which weeds must be controlled to prevent yield loss (Marten and Field, 1988; Oliver, 1979; Zimdahl, 1988). Economic thresholds are based on the yield produced under weed free conditions and can be used to help determine when to apply a herbicide. The economic threshold is when the weedy species reach a density such that the dollar value of crop yield gained by weed control is equal to the cost of the weed control (Coble and Mortensen, 1992; Cousens, 1987). Control is cost effective only at weed densities above the economic threshold (Bauer et al., 1991). Thresholds vary depending on crop and weeds present, resource availability and environmental conditions. Cardina et al. (1995) calculated economic thresholds ranging from 0.13 to 18.2 velvetleaf (*Abutilon theophrasti* Medicus.) plants m^{-2} in corn (*Zea mays* L.), depending on year and cost of inputs, tillage system and time of weed emergence. O'Donovan and Blackshaw (1997) calculated economic thresholds of 6 and 2 volunteer barley plants m^{-2} in peas for Vegreville, AB and Lethbridge, AB, respectively.

Weed and crop species compete differently, depending on the growing environment. Two different types of plants are the C-3 and the C-4 plant species, which describes the way CO_2 is converted to carbon compounds. Patterson and Flint (1983) compared soybeans and seven associated weeds with regards to water relations, photosynthesis and growth. Plant species were grown in controlled conditions with day and night temperatures of 32 / 23 $^{\circ}$C. The C-4 species in the experiment had the greater efficiencies in net photosynthesis, net assimilation rates and water use when compared to the C-3 species. The C-4 species did not always produce the highest plant weight or greatest leaf area. Both C-3 and C-4 species can become more competitive, depending on the environmental conditions and availability of resources. C-4 species exhibit higher rates of photosynthesis than C-3 species when exposed to high light, warm temperatures and drought stress (Ozturk et al., 1981; Salisbury and Ross, 1992). C-3 species are less competitive in lower ambient CO_2 levels than C-4 species. Patterson et al. (1984) increased the competitive ability of a C-3 crop, soybeans, against a C-4 weed, johnsongrass when they increased CO_2 levels from 350 parts per million (ppm) to 675 ppm. When C-3 and C-4 species are water stressed, increased CO_2 levels will also increase growth of both C-3 and C-4 species (Patterson, 1985). Ozturk et al. (1981) found that C-4 species' growth declined in high moisture situations and C-3 species' growth declined in drought conditions. Weaver (1984) compared three C-4 *Amaranthus* species to each other under three temperature regimes. The results indicated that as temperatures decreased C-4 species' growth decreased as well. Such a response limits C-4 species to certain climatic regions.

The lack of diversity within a field of crop plants as a monoculture, can leave considerable quantities of resources available for weedy species (Dekker, 1997). Knowing which weedy species are present in a field and the competitive ability of the crop towards the weeds present, can help producers to determine when weeds should be removed to prevent yield loss (Hall et al., 1992). Even if weeds are present and below the period and economic thresholds, they can still interfere with harvest (IPM Manual Group, 1986) or produce seed which can cause problems in later years.

Weeds can be controlled or supressed through mechanical, agronomic or chemical methods. With the implementation of Integrated Weed Management (IWM) programs that help producers to reduce herbicide use, methods of weed control are combined. Cultivation is the most common method of mechanical weed control. Research has shown inter-row cultivation to be most effective for early weed removal (Eadie et al., 1992; Murphy et al., 1996). Inter-row cultivation cannot be used by all producers or in all crops. Inter-row cultivation is limited to row crops in straight rows and relatively flat fields. It also dries the soil, and promotes weed-seed germination.

Agronomic variables useful for weed management include crop seeding rate and row width, time of seeding, and controlling fertility or irrigation. Weed competition can be surpressed or delayed by narrowing row widths and increasing crop densities (Carlson and Hill, 1985; Hume, 1989; Murphy et al., 1996; O'Donovan et al., 1988). However, by narrowing row width and increasing crop density, there is an increase in intra-specific competition within the crop. When corn is seeded, narrow row widths tend to increase yield whereas an increase in crop density may not give higher yields, but only decreases inter-specific competition between the weed and the crop (Murphy et al., 1996). Early seeding of the crop can allow the crop to become established and make the crop more competitive against late emerging weeds (Flint and Patterson, 1983). Limiting or adding water can change weed-crop competition depending on the particular crop and weeds. Some plant species are more efficient water users than other plants and can tolerate drought conditions. C-4 plant species are more negatively affected in higher moisture conditions than C-3 plant species (Ozturk et al., 1981). Under drought conditions, some C-4 species are more competitive than others. Red root pigweed, an annual, C-4 broadleaf is more competitive than corn, also a C-4 species, under dry conditions (Ball and Shaffer, 1993). Frequent irrigation can limit yield loss by decreasing the competitive ability of red root pigweed and increasing the competitive ability of corn. Increased moisture can also increase weed germination and change inter-speicific competition to favour the weed. The time period in which common ragweed (*Ambrosia artemisiifolia* L.) must be controlled for soybeans increased from two to four weeks as moisture availability increased (Coble et al., 1981). Dry weather prevented normal emergence of ragweed, a two week weed-free period was required to prevent yield loss. In wetter years, a four week weed-free period was required due to weeds that were constantly emerging. Common cocklebur (*Xanthium strumanium* L.) is more competitive with soybeans in high moisture conditions than in low moisture conditions (Mortensen and Coble, 1989). When giant foxtail was present in soybeans, moist conditions caused yield reductions in 10 to 15 days compared to 25 days in dry conditions after soybean emergence (Harrison et al., 1985). Soil fertility also affects weed-crop competition. In general, monocotyledonous weeds are more competitive at higher levels of soil nitrogen, phosphorous and potassium while dicotyledonous weeds are more competitive at lower levels of these three macronutrients (Banks et al., 1976).

Chemical methods of weed control include the application of herbicides either prior to planting [pre-plant incorporated (PPI)], after seeding but prior to crop emergence (pre-emergent), or after crop emergence (post-emergent). The availability of PPI, pre-emergent and post-emergent herbicides offer the advantage of being applied at different times, spreading the producer's work load throughout the field season. Depending on the PPI herbicide used, they can be applied with either fall or spring cultivation. Unfortunately, low moisture and dry conditions can decrease effectiveness of PPI and pre-emergent herbicides (Tapia et al., 1997). In addition, incorporation of PPI and pre-emergent herbicides can cause dry soil conditions. Post-emergent herbicides are applied when weeds have emerged and weed species and densities are known. Application of post-emergent herbicides can be determined based on the economic thresholds of weeds in a specific crop. Post-emergent herbicides have to be applied in good weather and some can only be applied at certain stages of the crop or the weed (Dunan et al., 1996; Jordan et al., 1993).

Once a herbicide is applied it may degrade quickly or slowly. PPI, pre-emergent and post-emergent herbicides that break down slowly may provide extended weed control due to residual effects, providing weed control while the crop is becoming established early in the growing season. However, some post-emergent herbicides have no residual effects and may have to be applied more than once to the crop throughout the growing season. If the herbicide is applied too early and there is no residual effect from the herbicide, the producer is putting the crop at risk to compete with a second growth of weeds, or second weed flush (Tapia et al., 1997). If a second flush occurs, then the producer may decide to make a second herbicide application. Tapia et al., (1997) showed that a later application of post-emergent herbicide gave similar or better weed control than an early post-emergent herbicide application. This was because weeds continued to emerge after herbicide application and later applications of post-emergent herbicide were required to control weeds. However, yields were lower from waiting to spray later in the season due to extended weed-crop competition. This makes it important to know if multiple applications of herbicides are practical and economical in order to increase weed control.

Researchers have studied the use of PPI, pre-emergent and post-emergent herbicides either alone or in combination or in sequence (Adcock et al., 1990; Byrd and York, 1987; Defelice, 1990; Jordan et al., 1993; Murray et al., 1994; Ratnayake and Shaw, 1992). Tank mixing more than one post-emergent herbicide or applying in sequence a PPI or pre-emergent and a post-emergent herbicide are ways of increasing chemical weed control and number of weeds controlled (Berti et al., 1996; Blackshaw and Harker, 1996; Byrd and York, 1987; Deflice, 1990 and Jordan et al., 1993). Berti et al., (1996) used a methodological approach to determine the optimal time to control velvetleaf (*Abutilon theophrasti* Medic.) and (*Amaranthus theophrasti* L.) weeds in corn and soybeans. They found that in a low weed population of 10 plants m^{-2}, two applications of post-emergent herbicide were more effective. However, as weed populations increased between 50 to 200 plants m^{-2}, the sequential application of a pre-emergent and two post-emergent herbicides was almost always the best strategy. Pre-emergent applications allow for greater flexibility in the applications of the following post-emergent treatments. However, the introduction of canola cultivars tolerant to non-selective, post-emergent herbicides, may alter the economics of applying PPI and pre-emergent herbicides prior to post-emergent herbicide applications.

Canola (*Brassica napus* L. and *B. rapa*) is a major oilseed crop grown throughout Canada. Canola is defined as rapeseed containing less than 2 % erucic acid and less than 30 μmole of glucosinolate per gram of oil-free meal. The high quality of oil obtained from canola, has led to increased demand and increased production of canola throughout the world. In 1994, 7.187 x 10^6 tonnes of canola were produced in Western Canada, making up about 16.2 % of the total production of the principle grains (wheat, oats, barley, rye, flax and canola) grown (Statistics Canada, 1995). The land base devoted to canola in Western Canada was approximately 14.165 x 10^6 acres or 25.8 % of the land used to produce the principle grains (Statistics Canada, 1995). Due to the value of canola to the agriculture industry, researchers are constantly striving to improve canola through the development of new cultivars to meet the demands of producers, processors and consumers. In the past, the development of new cultivars was achieved using traditional breeding methods. However, traditional breeding is a process that takes a very long time to make improvements to a crop and is limited to the use of sexually compatible species (Kung, 1993). With the introduction of transgenic methods, new cultivars are now being developed in a shorter time with characteristics that were difficult to achieve through traditional plant breeding techniques. Such methods have resulted in the release of herbicide-tolerant crops that contain foreign genes from non-sexually compatible species.

In the past, the introduction of a new herbicide was based on finding a chemical that would kill only the weeds but not damage the crop. The crop was tolerant and the weeds were susceptible to the herbicide. The herbicide was designed to control a number of weedy species in a particular crop or group of crops. However, by definition, non-selective herbicides kill most plant species, whether weed or crop. Plant breeders are taking susceptible crops and making them tolerant to non-selective herbicides. The recent introduction of canolas, tolerant to non-selective herbicides, that yield comparably to industry standard cultivars, provides producers with more options for their weed control programs. With non-residual, non-selective foliar applied herbicides like glyphosate or glufosinate ammonium, it is important to know when to apply the herbicide on the crop, and how many applications of herbicide will be required for adequate weed control.

The first herbicide-tolerant canola cultivars were triazine-tolerant developed through traditional breeding methods (hybridization), from crosses with sexually compatible triazine-tolerant weed species (Hall et al., 1996). The first triazine-tolerant cultivar was released in the mid 1980s and was known as " OAC Triton" (Beversdorf and Hume, 1984; Dyer, 1996). Other triazine-tolerant canola cultivars include "OAC Triumph", "Tribute" and "AC Tristar" (Beversdorf et al., 1988; McMullen et al., 1994; Hall et al., 1996). The use of these triazine-tolerant canolas was limited, however, due to their lower yield and delayed maturity when compared to industry standard cultivars. These characteristics were coupled to a mode of resistance: reduced photosynthetic electron transport decreased photosynthetic efficiency (Hall et al., 1996). Using these triazine-tolerant cultivars was therefore only advantageous when there was a heavy cruciferous weed infestation, or triazine residues in the soil. Furthermore, the use of triazine-tolerant cultivars declined with the introduction of ethametsulfuron (Muster®), which allowed producers to control heavy cruciferous weed infestations while using the higher yielding, triazine-susceptible cultivars.

Canola has now been developed with tolerance to other non-selective or broad spectrum herbicides besides the triazines. Plant breeders have used both transgenic and traditional plant breeding methods to develop herbicide-tolerant canola cultivars. There were three herbicide-tolerant canola groups marketed in 1997: 1) Roundup Ready® canola tolerant to glyphosate (Agriculture and Agri-Food Canada, 1995b), 2) Liberty Link® canola tolerant to glufosinate (Agriculture and Agri-Food Canada, 1995a), and 3) Smart Canola® tolerant to imidazolinone herbicides (Agriculture and Agri-Food Canada, 1995c).

The so-called Smart Canola® cultivars were developed without the use of transgenic methods, through chemically-induced somoclonal variation from microspore cultures. Breeders were able to alter the enzyme, acetolactate synthase (ALS), making the enzyme insensitive to imidazolinone herbicides

(Agriculture and Agri-Food Canada, 1995c). Therefore, the herbicide's active ingredient no longer blocked or prevented the formation of the branched chain amino acids isoleucine, leucine and valine within the tolerant plant (Agriculture and Agri-Food Canada, 1995c, Shaner and Little, 1991).

Transgenic methods were used to develop the glyphosate-tolerant canola, and the glufosinate ammonium-tolerant canola, through the transfer of genes from non-related species with the use of *Agrobacterium tumefaciens* vector (Agriculture and Agri-Food Canada, 1995a; Agriculture and Agri-Food Canada, 1995b). The glyphosate-tolerant canola contains two bacterial derived genes, the Roundup Ready^{TM} genes (Agriculture and Agri-Food Canada, 1995b). One gene reduces sensitivity to glyphosate at the active site, and the second gene produces an enzyme that degrades glyphosate giving the plant tolerance to it. Glyphosate is no longer able to inhibit the production of enolpyruvylshikimatephosphate synthase (EPSPS), which is an enzyme that catalyzes the formation of aromatic amino acids and secondary metabolites in plants (Klee et al., 1987). The glufosinate ammonium-tolerant canola contains the *pat* gene that was isolated from *Streptomyces viridochromogenes* (Agriculture and Agri-Food Canada, 1995a). This gene encodes the enzyme phosphinothricin-N-acetyl-transferase, which allows canola to detoxify phosphinothricin (the active ingredient of glufosinate ammonium) by acetylation, into inactive compounds, giving the plant tolerance to glufosinate ammonium (Agriculture and Agri-Food Canada, 1995a).

There are few published studies addressing weed-crop competition in canola. Many studies have focused on soybeans (Crook and Renner, 1990; Defelice, 1990; Harris and Ritter, 1987; Heatherly and Elmore, 1991; Mortensen and Coble, 1989; Toler et al., 1996), corn (Cardina et al., 1995; Knezevic et al., 1994; Murphy et al., 1996; Vangessel et al., 1995) and cotton (Brown et al., 1985; Oliver et al., 1991). Canola's competitive ability as a crop when compared to other crops varies, depending on the weeds present. When wild oat is present, canola is less competitive than barley but is similar in competitive ability to wheat (Dew, 1972; Dew, 1978; Dew and Keys, 1976; O'Donovan, 1988). When compared to other broad leaf crops, canola is more competitive than both peas and flax when competing with volunteer cereals. A study by Friesen et al. (1990) found flax yield losses were 49 % to 53 % when competing with 30 volunteer wheat plants m^{-2} and 56 % to 67 % when competing with 30 volunteer barley plants m^{-2}, depending on year. A similar study done by Marshall et al. (1989) using rapeseed as the crop showed that 30 volunteer wheat plants m^{-2} decreased rapeseed yield by 17 % and 30 volunteer barley plants m^{-2} decreased rapeseed yield 27 % to 35 % depending on year. O'Donovan and Blackshaw (1997) showed volunteer barley densities of 5 to 20 plants m^{-2} reduced pea yield 8 % to 27 %, whereas a study done by O'Donovan et al. (1988) suggested canola yield loss to be less for similar volunteer barley densities.

The use of herbicide-tolerant canola cultivars brings about many questions on how to use these crops effectively in the agriculture industry. PPI herbicides provide more options in weed control and early removal of weeds from the crop, however, post-emergent herbicides can be applied when weed populations are known. The work presented in this thesis will focus on the use of PPI and post-emergent herbicide applications and weed competition effects on the growth and yield of Roundup® herbicide-tolerant canolas to test the hypothesis: early weed removal in herbicide-tolerant canola with PPI ethalfluralin and post-emergent glyphosate combinations will increase yield of glyphosate-tolerant canola compared to yields from plots that received only single applications of glyphosate.

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Chapter 2 Wild Oat (*Avena fatua*) Competition Effects on Growth and Yield of Glyphosate-Tolerant Canola.

2.1 Introduction

Wild oat (*Avena fatua* L.) is a common weed that is a problem in annual crops grown in western Canada. Wild oat is an annual, C-3 grass, that can be very competitive with field crops and has been classified as one of the worst weeds throughout the world. Nalewaja (1977) estimated a loss of 6.4 million tonnes of wheat and barley yield throughout North America from wild oat infestations. Dew (1978) estimated in western Canada that there was a $280 million annual loss due to both the cost of wild oat control with herbicides, and crop yield loss due to wild oat competition. In 1995, producers in western Canada spent $698 million on herbicides for weed control in crops (Crop Protection Institute, 1996). In 1995, the total cost of herbicides used on wheat, barley and canola in western Canada was $637 million with approximately 50 % spent on herbicides applied for weed control in canola (Crop Protection Institute, 1996).

In the past, research on wild oat competition has mainly focused on competition with cereal crops, with little research on wild oat interference in canola (*Brassica napas* L. and *B. rapa* L.) (Cousens et al., 1991; Cudney et al., 1989a; Cudney et al., 1989b; Dunan and Zimdahl, 1991; Morishita et al., 1991; O'Donovan et al., 1985). Broadleaf weed research in canola has included work on common chickweed (*Stellaria media* L., Vill), scentless mayweed *(Matricaria inodora* L.*)*, Canada thistle (*Cirsium arvense* L. Scop.), lamb's quarters *(Chenopodium album* L.*)*, pale smartweed (*Polygonum lapathifolium* L.), and wild mustard *(Brassica kaber* [DC.] Wheeler var. *pinnatifida* [Stokes] Wheeler) (Blackshaw et al., 1987; Green and Savours, 1977; O'Donovan, 1994; O'Sullivan et al., 1985). Research on grass weed competition in canola included work on wild oat (*Avena fatua* L.), green foxtail (*Setaria viridis* L. Beauv.), volunteer wheat

(*Triticum aestivum* L.), volunteer barley (*Hordeum vulgare* L.), and quackgrass (*Agropyron repens* L. Beauv.) (Dew and Keys, 1976; Chow and Morrell, 1979; Marshall et al., 1989; O'Donovan, 1994; O'Donovan, 1991; O'Donovan et al., 1988; O'Donovan et al., 1989).

Researchers have studied crop-weed competition by studying time of weed emergence relative to crop emergence, and time of weed removal from the crop, at various weed densities. Most of the studies have focused on a single weed species within a crop monoculture. O'Donovan et al. (1985) studied the effect time of wild oat emergence on barley and wheat; they found a significant relationship between yield loss of both crops and time of wild oat emergence. The earlier the wild oat emerged (at a given density) with respect to emergence of the crop, the greater the yield loss from the crop. Time of emergence research on grassy weeds has also been carried out by Harris and Ritter (1987). They studied giant green foxtail (*Setaria viridis* var. *major* L.) and fall panicum (*Panicum dichotomiflorum* L.) in soybeans (*Glycine max* L.). Harris and Ritter (1987) found if plots were kept weed free for two weeks after soybean emergence, soybean yield would equal the yield from plots kept weed free throughout the growing season. Knake and Slife (1965) observed a reduction in soybean yield when giant green foxtail emerged at the same time as soybeans. However, if giant green foxtail emerged three weeks after soybeans emerged, there was no reduction in soybean seed yield. Soybeans were able to out-compete giant green foxtail. The length of time required to keep the crop weed free to eliminate yield loss is the critical period.

Canola (rapeseed)-weed competition studies have been done by Blackshaw et al. (1987), Marshall et al. (1989), O'Donovan (1991), O'Donovan et al. (1988), O'Donovan et al. (1989) and O'Sullivan et al. (1985). These studies investigated the effect of weed densities have on canola yield. Blackshaw et al.

(1987) showed that wild mustard interfered with rapeseed dry matter production more than did lamb's quarters. Approximately 40 days after rapeseed emergence, both weeds at 20 plants m^{-2} caused significant reductions in rapeseed dry weight. Increased weed density caused further reductions in both yield and dry matter production of rapeseed. Weed densities of 20 to 80 plants m^{-2} reduced yield of rapeseed from 19 % to 77 % with wild mustard, and from 20 % to 25 % with lamb's quarters. Both weeds interfered with canola growth early in the growing season. O'Donovan et al. (1988) studied volunteer barley interference in canola. They showed that canola yield decreased as volunteer barley density increased. At the lower volunteer barley densities, canola yield loss due to increasing volunteer barley densities was nearly linear, each volunteer barley plant had a similar effect on yield loss. At higher barley densities, canola yield loss per volunteer barley plant was not as great due to increased intra-specific competition within the barley, canola yield loss was no longer linear with increasing volunteer barley density. Canola yield losses ranged from 18 % to 30 %, depending on canola seeding rate, for 40 volunteer barley plants m^{-2}. At 200 volunteer barley plants m^{-2}, canola yield loss ranged from 50 % to 64 %. Canola yield losses were not as great as volunteer barley densities increased beyond 200 plants m^{-2}, reflecting increased intra-specific competition between the volunteer barley (O'Donovan et al., 1988). Marshall et al. (1989) showed that 30 volunteer wheat plants m^{-2} reduced canola yield by 17 % and that an equivalent density of volunteer barley reduced yield by 27 %. O'Donovan et al. (1989) showed that volunteer wheat at 30 plants m^{-2} caused approximately 9 % and 25 % yield losses with canola at 200 and 50 plants m^{-2}, respectively. Increasing the crop density decreased the competitive effect of the volunteer wheat. O'Sullivan et al. (1985) studied competition effects of Canada thistle on canola and found that Canada thistle was more competitive than volunteer cereals. Canada thistle populations of 10 to 20 shoots m^{-2} were capable of causing a 10 % to 25 % decrease in canola yield. O'Donovan

(1991) studied the competitive effects of quackgrass on canola yield. Moderate quackgrass infestations of 50 to 100 shoots m^{-2} reduced canola yield by 18 % to 32 %. Yield loss of canola caused by quackgrass interference was similar to that caused by wild oat interference (Dew and Keys, 1976 and O'Donovan, 1991). Dew and Keys (1976) developed an equation from which they estimated that a 100 wild oat plants m^{-2} decreased canola yield by 32 %. Previous research showed that while volunteer wheat and barley were similar in competitive ability, they were more competitive than wild oat, and less competitive than Canada thistle (Marshall et al., 1989; O'Donovan et al., 1988; O'Donovan et al., 1989).

Only a few studies have examined the effect of time of weed removal from canola using herbicides. Forcella (1987) and McMullan et al. (1994) both studied time of weed removal in triazine-tolerant canolas. McMullan et al. (1994) showed that wild mustard decreased harvested seed yield of canola, and that the presence of wild mustard seed contaminated the canola oil by increasing the glucosinolate content. Canola yields were highest when wild mustard was removed at the earliest opportunity (McMullan et al., 1994). Forcella (1987) studied weed density thresholds to determine when it was economical to use a triazine tolerant canola variety over a triazine-susceptible variety. Triazine-tolerant canola varieties were generally lower yielding than triazine-susceptible varieties. Forcella (1987) showed that 25 to 30 wild oat m^{-2} resulted in a 17 % yield loss which was sufficient to warrant the use of the tolerant variety.

The objective of this study was to determine the effect of time of weed removal by herbicides on the yield of canola at two sites in Alberta. Weed control was achieved using pre-plant incorporated (PPI) ethalfluralin and post-emergent glyphosate applications on glyphosate-tolerant canola. Competition effects of wild oat, natural weed infestations, and times of herbicide applications were studied. The purpose of this field research was to examine the effect of time of wild oat removal on canola yield, using PPI ethalfluralin and post-emergent glyphosate in sequence and alone. More specifically, does PPI ethalfluralin improve weed control with glyphosate, does one glyphosate application provide adequate weed control, and does an early application of glyphosate increase yield compared to a late application of glyphosate.

2.2 Method and Materials

2.2.1 Locations

The experiment was conducted in 1996 and 1997 at the Alberta Research Council, Vegreville, AB., and at the Agriculture and Agri-Food Canada Research Station, Lacombe, AB. (Table 2.1). At each location, wild oat was seeded to achieve a constant distribution of the weed throughout the plot area, at either a high or low weed density. Weather records from Environment Canada were retrieved for each location. Weekly averages for 1996 and 1997 and 40 year (plus) averages for precipitation and air temperatures were recorded (Appendix 7.3).

Table 2.1 Site description for wild oat trials at Vegreville and Lacombe for 1996 and 1997.

Site and Year	**Vegreville 1996**	**Vegreville 1997**	**Lacombe 1996**	**Lacombe 1997**
Previous Cropping History	Fallow	Cereal Cover Crop	Fallow	Fallow
Soil Texture*	sandy loam - loam	sandy loam - loam	sandy clay loam	sandy clay loam
Sand	57 %	57 %	59 %	59 %
Silt	30 %	30 %	15 %	15 %
Clay	13 %	13 %	26 %	26 %
Organic Matter*	3.8 % - 6.8 %	3.8 % - 6.8 %	8 % - 9 %	8 % - 9 %
pH*	5.9 - 7.0	5.9 - 7.0	5.5 - 6.1	5.5 - 6.1

*based on top 15 cm of soil horizon.

2.2.2 Experimental Design

The experimental design was a split, split randomized block design with six replications. The main plots were PPI herbicide treatments, the sub plots were weed densities and the sub, sub plots were post-emergent herbicide treatments and a hand-weeded check. The PPI treatments were either ethalfluralin or no ethalfluralin, and the weed densities were either low or high wild oat density. The five treatments were post-emergent glyphosate applied as an early application, late application, an early and late application (a double application of glyphosate applied at an early and late stage of canola), a weedy control with no post-emergent herbicide application, and a hand-weeded check (Tables 2.2, 2.3, and 2.5).

2.2.3 Herbicide Application

Ethalfluralin (a 60 % active ingredient (a.i.) dispersible concentrate formulation) [N-ethyl-N-(2-methyl-2-propenyl)-2,6-dinitro-4-(trifluoromethyl) benzenamine] (w / w) was applied PPI at 1100 g a.i. ha^{-1} at Vegreville and at 1400 g a.i. ha^{-1} at Lacombe. Rates of ethalfluralin were calculated based on soil type, soil texture and organic matter (Tables 2.1, 2.2 and 2.3). Once the ethalfluralin was applied PPI in the spring, the area was disced twice to a depth of 10 to 12 cm, the first discing going length wise, and the second discing at right angles to the first. Both the treated and untreated areas of ethalfluralin were disced with a tandom disc and then harrowed with diamond toothed harrows. The ethalfluralin was incorporated into the soil surface, and the area then harrowed to smooth out the trial after discing. Liquid glyphosate [N-(phosphonomethyl)glycine] 356 grams liter^{-1} (g L^{-1}) acid equivalent (a.e.) was the post-emergent herbicide used. Glyphosate, a foliar applied, non-selective post emergent herbicide, was applied at 450 g a.e. hectare^{-1} (ha^{-1}) or 0.5 L acre^{-1}. Glyphosate was applied at approximately the 2 to 3 leaf stage (early glyphosate treatment) and at the 5 to

6 leaf stage of canola (late glyphosate treatment), but varied depending on weather conditions (Tables 2.2, and 2.3).

Table 2.2 Vegreville 1996 and 1997 spray information for wild oat trial.

Herbicide	**Pre-Plant Incorporated**		**Post-Emergent**					
Year	**1996**	**1997**	**1996**			**1997**		
Compound	Ethalfluralin (Edge® 60 DC)		Glyphosate (Roundup® 356 SL)					
Appl. Timing	Prior to Seeding		Early	Late	Early / Late	Early	Late	Early / Late
Canola leaf stage	-	-	2 - 3	5	2-3 / 5	2 - 3	6 - 7	2-3 / 6-7
Appl. Date	May-15	May-13	Jun-12	Jun-27	Jun-12 / 27	Jun-14	Jun-24	Jun-14/25
Rate of a. i. (g / ha)	1100	1100	450*	450*	450* / 450*	450*	450*	450* / 450*
Soil Temp °C[1]	7.0	10	-	-	-	16	19	16/19
Air Temp °C	-	15	20	7.5	20/7.5	20	20	20/20
% Humidity	-	-	25	98	25/98	78	95	78/95
Weather on spray day	snow / rain	sunny	sunny	foggy	sunny / foggy	sunny	cloudy	sunny / cloudy
Sprayer	Tractor CO_2	Tractor CO_2	Bicycle CO_2	Bicycle CO_2	Bicycle CO_2	Bicycle CO_2	Bicycle CO_2	Bicycle CO_2
Ground Speed (km/hr)	7.3	7.3	4.0	4.0	4.0	4.0	4.0	4.0
H_2O Vol. (L ha^{-1})	131	131	110	110	110	110	110	110
Nozzle	8002	8002	11001	11001	11001	11001	11001	11001
# Nozzles	4	4	4	4	4	4	4	4
Screens	50	50	100	100	100	100	100	100
k Pa	278	278	278	278	278	278	278	278

*rate calculated using acid equivalent.

[1] temperature taken at a depth to 5 cm.

Table 2.3 Lacombe 1996 and 1997 spray information for wild oat trial.

Herbicide	**Pre-Plant Incorporated**		**Post-Emergent**					
Year	**1996**	**1997**	**1996**			**1997**		
Compound	Ethalfluralin (Edge® 60 DC)		Glyphosate (Roundup® 356 SL)					
Appl. Timing	Prior to Seeding		Early	Late	Early / Late	Early	Late	Early / Late
Canola leaf stage	-	-	3 - 3.5	5 - 6	3-3.5 / 5-6	2 - 3	5	2-3 / 5
Appl. Date	May-24	Apr-30	Jun-27	Jul-2	Jun-27 / Jul-2	Jun-7	Jun-16	Jun-7 / 16
Rate of a. i. (g / ha)	1100	1100	450*	450*	450* / 450*	450*	450*	450* / 450*
Soil Temp $^{o}C^{1}$	15	-	-	-	-	-	-	-
Air Temp ^{o}C	13	-	12	15	12 / 15	12	20	12 / 20
% Humidity	-	-	85	78	85 / 78	-	-	-
Weather on spray day	sunny	sunny	cloudy	sunny	cloudy / sunny	sunny	cloudy	sunny / cloudy
Sprayer	Tractor CO_2	Tractor CO_2	Small Plot CO_2	Small Plot CO_2	Small Plot CO_2	Small Plot CO_2	Small Plot CO_2	Small Plot CO_2
Grnd Spd (km/hr)	7.3	7.3	4.0	4.0	4.0	4.0	4.0	4.0
H_2O Vol. (L ha^{-1})	131	131	110	110	110	110	110	110
Nozzle	8002	8002	8001	8001	8001	8001	8001	8001
# Nozzles	4	4	4	4	4	4	4	4
Screens	50	50	100	100	100	100	100	100
k Pa	278	278	278	278	278	278	278	278

*rate calculated using acid equivalent.

[1] temperature taken at a depth to 5 cm.

2.2.4 Plant Establishment

The Round-up® - tolerant canola cultivar 'Quest'® was used during both field seasons. 'Quest' is an Argentine canola (*Brassica napus* L.) variety which contains the Round-up Ready™ genes (Agriculture and Agri-Food Canada, 1995). The seed was treated with Vitavax®rs flowable, which contains carbathiin, thiram and lindane. The wild oat seed was obtained from the Agriculture and Agri-Food Canada Research Station in Lacombe. Wild oat was seeded using a small-plot, double disc press drill (Table 2.4). The entire plot was seeded to the low density of 50 seeds m^{-2} and then the seed drill went over the plot a second time seeding only the high density plots with a further 150 seeds m^{-2} which gave a final density of approximately 200 seeds m^{-2}. Germination rate of wild oat was 95 %. Canola was cross-seeded at right angles to the wild oat, at 6 kg ha^{-1} to a depth of 2.5 to 3.0 cm, using a small-plot, double disc press drill (Table 2.4). The trial was then harrowed twice to break up the seed rows and mix the seeds into the top 5 cm of the soil.

Table 2.4 Vegreville and Lacombe 1996 and 1997 summary for wild oat trial preparation.

Location	**Vegreville**				**Lacombe**			
Year	**1996**		**1997**		**1996**		**1997**	
Plant Seeded	WO**	Canola	WO**	Canola	WO**	Canola	WO**	Canola
Seeding Date	May-17	May-17	May-16	May-20	May-24	May-28	May-6	May-9
Seeder	double disc press drill	double disc press drill	double disc press drill	double disc press drill	double disc press drill	double disc press drill	double disc press drill	double disc press drill
Seeding Rate	50/200*	6 kg/ha	50/200*	6 kg/ha	50/200*	6 kg/ha	50/200*	6 kg/ha
Seeding Depth	3 cm	2.5 cm	3 cm	2.5 cm	3 cm	2.5 cm	3 cm	2.5 cm
Row Width	18 cm	18 cm	18 cm	18 cm	23 cm	23 cm	23 cm	23 cm
Fertilizer 12-51-00 banded	-	50 kg/ha	-	50 kg/ha	-	28 kg/ha	-	28 kg/ha
Desiccant ***	-	no	-	yes	-	no	-	yes

* low density seeded at 50 plants m^{-2} / high density seeded at 200 plants m^{-2}.

** WO - Wild oat.

*** Reglone® used as desiccant prior to harvest.

Table 2.5 Vegreville and Lacombe 1996 and 1997 summary for wild oat hand-weeded treatments.

Location	**Vegreville**				**Lacombe**			
Year	**1996**		**1997**		**1996**		**1997**	
	1st Hand-weeding	2nd Hand-weeding	1st Hand-weeding	2nd Hand-weeding	1st Hand-weeding	2nd Hand-weeding	1st Hand-weeding	2nd Hand-weeding
Day	Jun-3	Jun-12	Jun-4	-	Jun-10	Jun-17	May-29	Jun-5
Canola leaf stage	cotyledon	-	cotyledon	-	cotyledon - I leaf	-	cotyledon	-
Weed leaf stage	1-2 leaf	-	1-leaf		1-2 leaf	-	1 leaf	-

2.2.5 Data Collection

A visual rating of weed survival was conducted 2 weeks after the last application of glyphosate. The rating was based on % weed biomass left in each treatment compared to the untreated controls - 100 % representing complete weed control, 0 % representing no weed control. Harvested yield was obtained using a small plot combine to harvest canola from plot areas of 7.4 m by 1.4 m in Lacombe and 8.0 m by 1.2 m in Vegreville. Plots were harvested at seed maturity in early to late September. In 1996, each harvested sample was dried to constant moisture level of 5.5 % to 6.5 %, cleaned with sieves and weighed. In 1997, a weigh unit was attached to the small plot combine that measured yield and % moisture from each treatment during harvest. Sub-samples were collected and cleaned to determine dockage. Dockage was only found in sub-samples of plots that had not received an application of herbicide. Dockage ranged from 7 % to 20 %.

2.2.6 Data Analysis

Analysis of variance was performed on all parameters measured using SAS General Linear Model (GLM) procedure to determine significant interactions (SAS Institute Inc. 1996). The probabilities of differences between means were calculated using the PDIFF option of the LSMEANS procedure. All means were compared at ($P<0.05$) level.

2.3 Results and Discussion

At Lacombe and Vegreville in 1996 and 1997, wild oat and other weed species emerged at the same time as, or after, canola emergence. All weed populations were recorded at the time of the second glyphosate application (Tables 7.1.20 to 7.1.23). Wild oat grew vigorously with the canola and elongated above the crop canopy. Lamb's quarters and stinkweed (*Thlaspi arvense* L.) were two other weeds present at various densities throughout the trial at both locations. Lamb's quarters also elongated above the crop canopy and stink weed grew to the same height as the canola. Wild oat, lamb's quarters, and stinkweed all reached population levels that have previously been shown to cause crop yield reductions (Blackshaw et al., 1987, Dew and Keys, 1976 and O'Donovan et al., 1989). Canola yields were higher at both locations in 1996 compared to 1997 (Table 7.1.2). Plots at Lacombe out-yielded those at Vegreville in both 1996 and 1997 (Table 7.1.2).

Weekly precipitation and temperatures for both years were recorded (Tables 7.3.3 to 7.3.6). Monthly precipitation and temperature means for location (40 year (plus) averages) and for the 1996 and 1997 growing seasons are plotted together (Figures 7.3.1 to 7.3.4). The temperatures at Lacombe and Vegreville for 1996 and 1997 were slightly below the 40 year average. Temperatures for 1997 were cooler in April at both locations and then increased to approximately the 40 year average. Temperature means for the two field seasons were higher in Vegreville than in Lacombe (Figures 7.3.5 to 7.3.8). In 1997, Vegreville did not become warmer than Lacombe until after the last week of April, then temperatures were generally warmer in Vegreville throughout the remainder of the growing season.

The precipitation at both locations was generally above the 40 year averages (Figures 7.3.2 and 7.3.4). There was more precipitation in the 1996 than in the 1997 growing season (Tables 7.3.3 to 7.3.6). On average, Lacombe received more precipitation than Vegreville (Figure 2.1). In 1996, by the end of May, Lacombe had received 148 mm and Vegreville 62 mm of rain. By the end of July, 1996, Lacombe had received 380 mm and Vegreville 224 mm of rain. By the end of May, 1997, Lacombe had received 78 mm and Vegreville 91 mm of rain; however, by the end of July Lacombe had received 267 mm and Vegreville 239 mm of rain.

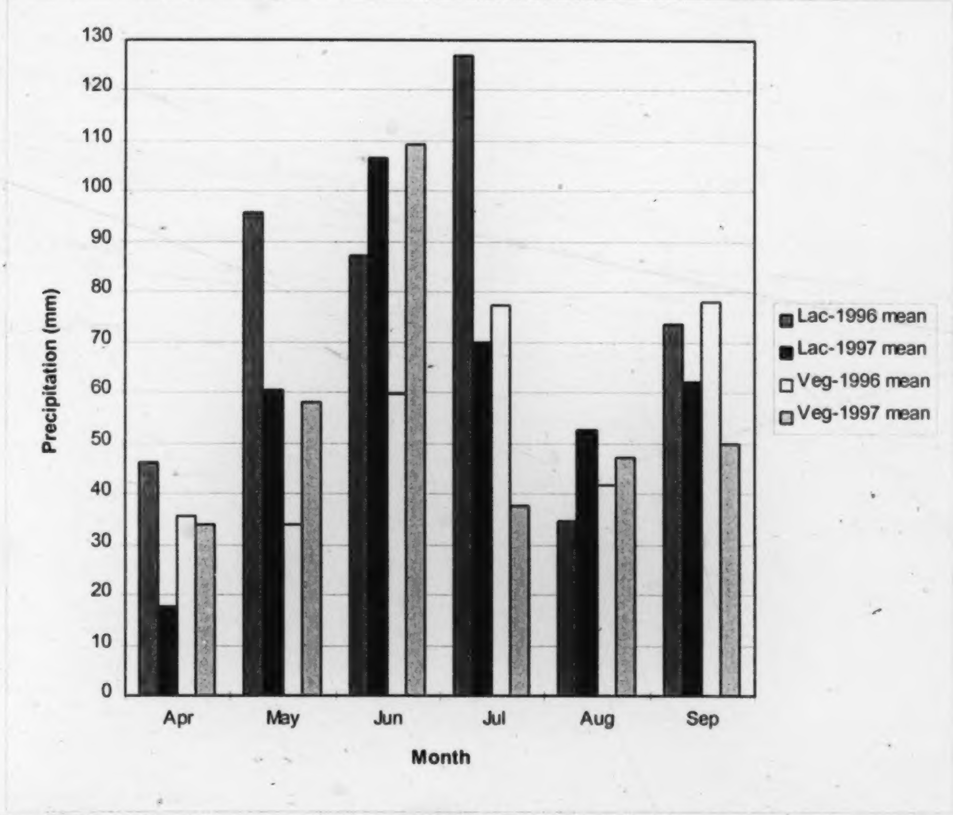

Figure 2.1 Monthly precipitation for 1996 and 1997 field seasons at Lacombe and Vegreville.

Weed control by ethalfluralin or glyphosate was very effective at both locations. Overall, ethalfluralin controlled wild oat 95 % and glyphosate controlled wild oat 99% (Tables 7.1.24 and Table 7.1.25). The few wild oat plants that emerged in the ethalfluralin plots were two or more leaf stages behind the wild oat in the untreated checks. Late applications of glyphosate, either alone, or after an early application of glyphosate, caused discoloration of the canola leaves and delayed flowering. This response was more noticeable at Lacombe. The lighter yellow flowers could have been due to a delay in flowering or a discoloration of the flowers.

Analysis of variance for canola yield indicated a number of significant interactions (Table 7.1.1). Table 7.1.1 showed that significant interactions included trial (site x year), between PPI herbicide, wild oat density and glyphosate treatments; therefore, data were presented separately for each trial. Further analysis of variance indicated that interactions occurred due to the weed-free check and the weedy-check; therefore, glyphosate treatments were analyzed separately. Analysis of glyphosate treatments showed significant trial by treatment interaction; therefore, trials were analyzed separately as Lac '96, Veg '96, Lac '97 and Veg '97 (Table 2.6). Comparisons relevant to this study were made between the canola yield means from the significant ethalfluralin and glyphosate treatments (Table 2.7).

Table 2.6 Summary of analysis of variance for canola yield from plots treated with glyphosate for 1996 and 1997 field seasons at Lacombe and Vegreville.

Source	**Lac '96**	**Veg '96**	**Lac '97**	**Veg '97**
Replication	--	--	--	--
PPI Herbicide (H)	0.82	0.10	0.04	0.31
Error				
Density (D)	0.57	0.86	0.30	0.16
D x H	0.74	0.63	0.33	0.98
Error				
Treatment (Tr)	0.04	0.020	0.30	0.01
Tr x H	0.32	0.14	0.08	0.34
Tr x D	0.86	0.66	0.41	0.49
Tr x D x H	0.18	0.40	0.14	0.20
Error				

Table 2.7 The effect of time of glyphosate application and ethalfluralin on canola yield for each trial.

Treatment		Lacombe 1996	Vegreville 1996	Lacombe 1997	Vegreville 1997
Number	**Herbicide**	**Yield (kg ha^{-1})**	**Yield (kg ha^{-1})**	**Yield (kg ha^{-1})**	**Yield (kg ha^{-1})**
1	E glyph	4554	4648	4165	4091
2	E / L glyph	4255	4585	3958	4118
3	L glyph	4517	4453	4098	3764
	standard error	**90**	**50**	**95**	**89**
4	Ethalfluralin*	4422	4655	4150	4052
5	No Ethalfluralin*	4462	4469	3997	3931
	standard error	**120**	**70**	**41**	**76**
Contrasts		**Pr**	**Pr**	**Pr**	**Pr**
1 vs 2		0.025	0.38	0.13	0.83
1 vs 3		0.77	0.01	0.62	0.013
2 vs 3		0.047	0.07	0.31	0.008
4 vs 5		0.80	0.12	0.04	0.31

* means averaged over glyphosate treatments.

E glyph = early application of glyphosate. L glyph = late application of glyphosate. E / L glyph = early and late applications of glyphosate.

2.3.1 Lacombe, 1996

The early application of glyphosate to canola plots resulted in yield similar to that harvested from plants that had received a late application of glyphosate (Table 2.7). The early / late application of glyphosate to canola significantly decreased canola yield when compared to the early or late application of glyphosate alone (Table 2.7). An application of ethalfluralin prior to the application of glyphosate had no significant effect on canola yield (P=0.80) (Table 2.7). Canola yield harvested from the weedy-check (3627 kg ha^{-1}) (Table 7.1.12) was lower than canola yield harvested from plots that had been treated with ethalfluralin (4457 kg ha^{-1}) (Table 7.1.12) or glyphosate (Table 2.7). Wild oat density did not have an effect on canola yield harvested from plots treated with a herbicide (Table 2.6). Canola from the weedy-checks yielded 3057 kg ha^{-1} and 4195 kg ha^{-1} (Table 7.1.16) for high and low wild oat densities, respectively, which illustrates the effects that season-long weed competition, and weed density had on yield. Yield loss ranged from 8 % to 33 % for low to high weed density, respectively, compared to yield achieved with early application of glyphosate (Table 2.7). The application of a herbicide, either ethalfluralin or glyphosate controlled wild oat. When no ethalfluralin or glyphosate was applied, canola yield decreased as wild oat density increased.

2.3.2 Vegreville 1996

Canola yield from the early application of glyphosate was significantly higher than canola yield harvested from plots that had been treated with only a late application of glyphosate (P=0.01) (Table 2.7). Yield decreased approximately 4 % when weeds competed with the canola from the 2 leaf to 6 leaf stage of canola. This differs from the results obtained at Lacombe in 1996, where yields tended to be lower with the double glyphosate application and yields from the early and late application of glyphosate were similar. The application of ethalfluralin prior to glyphosate did not increase canola yield (P=0.12) (Table 2.7). When herbicides were used, canola yield did not differ between high and low wild oat densities. Wild oat only caused significant decreases in canola yield when not controlled by a herbicide. Canola yield from the weedy-checks were 2140 kg ha^{-1} and 2906 kg ha^{-1} for high and low wild oat densities, respectively (Table 7.1.18) Yield losses ranged from 37 % to 54 % for low and high wild oat densities, respectively when compared to yield harvested from the early application of glyphosate (Table 2.7). The greater yield loss between the untreated high and low wild oat density treatments at Vegreville compared to Lacombe in 1996 may have been due to the slightly higher weed densities (Table 7.1.20 and 7.1.22) and drier conditions at Vegreville.

2.3.3 Lacombe 1997

Canola yield from glyphosate treated plots were not significantly different (Table 2.7). The application of ethalfluralin prior to glyphosate significantly increased yield. Wild oat density did not affect canola yield when herbicides were used.

Canola yield from the weedy-checks were 2207 kg ha^{-1} and 3518 kg ha^{-1} from high and low wild oat densities, respectively (Table 7.1.17). Yield losses from canola growing in low and high weed densities ranged from 15 % to 47 %, respectively, when compared to yield achieved with an early application of glyphosate (Table 2.7).

2.3.4 Vegreville 1997

Canola yield from plots that had received the early application and the early / late application of glyphosate were not significantly different from each other (Table 2.7). Canola yield from plots that had received the late application of glyphosate was significantly lower than that from plots that had received either the early or early / late application of glyphosate. Yield decreased approximately 8 % when weeds competed with the canola from the 2 leaf to the 6 leaf stage. The application of ethalfluralin prior to glyphosate applications did not have a significant effect on canola yield. Wild mustard was present and was not controlled by ethalfluralin. An early application of glyphosate was required to remove the weed pressure. Wild oat density did not affect yield when herbicides were used. Canola yield from the weedy-checks were 2406 kg ha^{-1} and 2868 kg ha^{-1} from high and low wild oat densities, respectively (Table 7.1.19). Yield losses from canola growing within low and high weed densities ranged from 30 % to 41 %, respectively, when compared to yield achieved with an early application of glyphosate (Table 2.7).

Early and effective weed control is required inorder to maximize yields. Research by Kirkland (1995) on removal of wild mustard from canola with HOE 075032 showed that later weed removal and crop injury decreased canola yield. The early application of herbicide was most effective at controlling wild mustard. A later application of herbicide resulted in poorer weed control, and an increased herbicide rate injured the canola, which further decreased yield. The highest yield was achieved from the early applications of herbicide, and the least crop injury occurred in drier than normal growing seasons. At Lacombe, the double glyphosate application decreased canola yield when compared to the single application of glyphosate, suggesting herbicide injury to the canola. At Vegreville this injury to the canola was not observed, which suggest that increased optimal growing conditions (such as Lacombe) may lead to crop injury from multiple applications of glyphosate. Further investigation of growing conditions with regards to the effects of multiple glyphosate applications is required.

Pre-plant incorporated ethalfluralin did not always result in a yield advantage. Weeds did not continue emerging in the canola. Canola has a shorter growing season than some crops and the leaf canopy closes quickly making canola competitive towards weeds. Research by Jordan et al., (1993) on cotton, showed that the untreated control and an early application of sethoxydim resulted in the lowest cotton yields. A second flush of weeds occurred after the early application of sethoxydim, weeds competed with the crop and decreased harvested yield. The highest yield came from plots that had been treated with the sequential applications of a PPI (trifluralin), a pre-emergent (fluometuron) and a post-emergent (methazole + MSMA). An early application of both sethoxydim and DPX-PE350 and an early sethoxydim and a mid application of DPX-PE350 resulted in similar yields. An early application of sethoxydim and a late application of DPX-PE350 resulted in significantly lower yields than that from earlier post-emergent treatments. Yield reductions were due to increased time of weed competition and poor weed control. At Lacombe, the early application of glyphosate resulted in the highest canola yield and at Vegreville, the early or the early / late application of glyphosate resulted in the highest canola yields. The application of PPI ethalfluralin only produced a significant advantage at Lacombe, 1997.

A difference was observed between canola yields at, Lacombe and Vegreville and timing of glyphosate applications for both field seasons (Figures 2.2, 2.3, 2.4, and 2.5). At Lacombe 1996, canola yield from the early / late application of glyphosate was significantly lower than that from the early or late applications of glyphosate (Table 2.7). The glyphosate treatments in Vegreville for both years differ from the results obtained at Lacombe. In Lacombe the early / late application gave significantly lower yields than the early application of glyphosate (Table 2.7). The differences at location between the single and the double application may be due to drier conditions at Vegreville, which may have prevented injury from the double application of glyphosate. Past studies have shown that post-emergent herbicides controlled weeds less effectively under dry soil conditions (Boydston, 1990; Vidrine et al., 1993). Glyphosate may be more active in areas with optimal growing conditions and may have caused increased damage to the canola plants when applied as an early / late application. Lacombe has increased organic matter and receives more precipitation than Vegreville. This same effect has been observed with other herbicides. Boydston and Slife (1987) showed that atrazine controlled giant green foxtail more effectively when plants were not moisture stressed, showing triazine to be more active in moist conditions. Kirkland (1995) showed canola injury increased following an application of post-emergent HOE 075032 when conditions were wetter than usual. At Vegreville, the drier growing conditions may have decreased glyphosate damage to the canola, enabling the crop to take advantage of the early weed removal resulting from the early / late application of glyphosate.

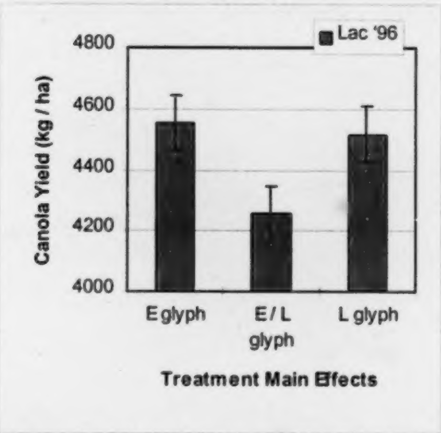

Figure 2.2 Glyphosate treatments for Lacombe 1996. Treatments included early application of glyphosate (E Glyph), early / late application of glyphosate (E/L glyph) and late application of glyphosate (L Glyph). Treatment means were averaged over PPI herbicide and wild oat densities. Standard error of the means was 90 kg ha^{-1}.

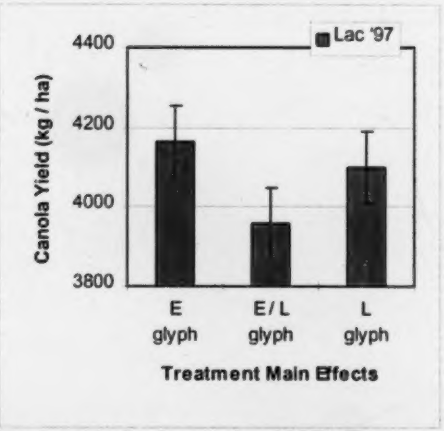

Figure 2.3 Glyphosate treatments for Lacombe 1997. Treatments included early application of glyphosate (E Glyph), early / late application of glyphosate (E/L glyph) and late application of glyphosate (L Glyph). Treatment means were averaged over PPI herbicide and wild oat densities. Standard error of the means was 95 kg ha^{-1}.

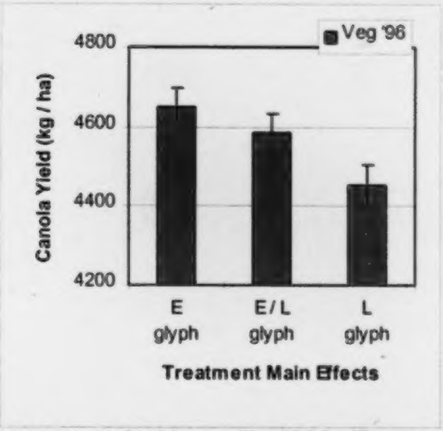

Figure 2.4 Glyphosate treatments for Vegreville 1996. Treatments included early application of glyphosate (E Glyph), early / late application of glyphosate (E/L glyph) and late application of glyphosate (L Glyph). Treatment means are averaged over PPI herbicide and wild oat densities. Standard error of the means was 50 kg ha^{-1}.

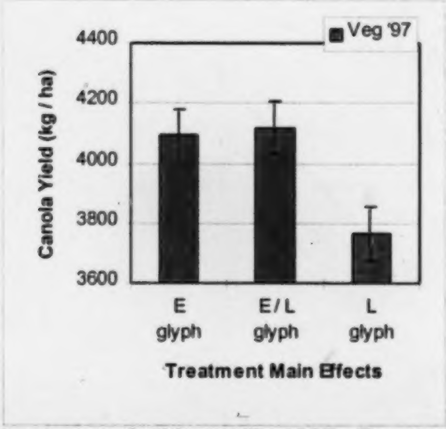

Figure 2.5 Glyphosate treatments for Vegreville 1997. Treatments included early application of glyphosate (E Glyph), early / late application of glyphosate (E/L glyph) and late application of glyphosate (L Glyph). Treatment means were averaged over PPI herbicide and wild oat densities. Standard error of the means was 89 kg ha^{-1}.

2.4 Conclusions

1. The results suggest that in areas with optimal growing conditions and in the absence of a second flush of weeds (such as Lacombe), the double application of glyphosate was not effective in increasing canola yield compared to either an early or a late application of glyphosate. At Lacombe, plots that received an early application, or a late application of glyphosate, had higher canola yields compared to plots that had received the early / late application of glyphosate. At Lacombe, the two sequential applications of glyphosate appeared to significantly reduce canola yield compared to the single applications of glyphosate.

2. In most cases, the sequential application of ethalfluralin prior to glyphosate on canola plots did not result in a significant yield increase. Glyphosate may be applied early enough to prevent significant yield loss.

3. When weeds were successfully controlled by herbicide application early in the crop life cycle, there was no significant difference in crop yield response between the high and low weed densities.

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Chapter 3 Red Root Pigweed (*Amaranthus retroflexus*) Competition Effect on Growth and Yield of Glyphosate-Tolerant Canola.

3.1 Introduction

Red root pigweed (*Amaranthus retroflexus* L.) is a common weed that is found throughout Canada's agriculture production areas (Weaver and McWilliams, 1980). Red root pigweed is an annual, C-4 broadleaf that can be a very competitive weed in certain field crops and growing conditions (Knezevic et al., 1994; Dieleman et al., 1995). A field survey conducted by Frick and Thomas (1992) during 1988 - 1989 in Southern Ontario, ranked red root pigweed as the fourth most common weed. Red root pigweed was found in 25 % of the fields surveyed. Swinton et al. (1994), citing work from other weed scientists, indicated that red root pigweed is as competitive as lamb's quarters (*Chenopodium alba* L.) in corn (*Zea mays* L.), in the major corn-soybean (*Glycine max* L) growing areas of the USA.

Competition between plant species can occur intra-specifically or inter-specifically. Inter-specific competition is when two different plant species are competing for the same environmental resources (light, moisture and nutrients). Intra-specific competition is when there is only one plant species competing for the same resources. The competitive ability of weeds changes, depending on the resources available and favorable conditions (temperature and soil pH). Yield loss of a crop due to weed-crop competition depends on the time of weed emergence with respect to crop emergence, the length of time weeds are allowed to compete with the crop and the weed density. The critical period is the time period in which weeds must be controlled to prevent yield loss (Weaver and Tan, 1983; Zimdahl, 1988). When yield loss equals the cost of weed control, then the economic threshold is reached (Cousens, 1987). At the economic threshold, it is cost effective to apply some form of weed control. To determine economic thresholds and critical periods, it is important to know the competitive abilities of weeds at certain densities, and how the time of weed emergence will affect the crop. After seeding, weeds may emerge from the seed bed at the same time as the crop, or later in the growing season after the crop has become established. Time of weed emergence may affect the crop by increasing or decreasing economic thresholds and critical periods.

Research on red root pigweed in weed-crop competition, has been done by Dieleman et al. (1996), Dieleman et al. (1995), Knezevic et al. (1994), Swinton et al. (1994), Vangessel and Renner, (1990) and Vangessel et al. (1995). Vangessel et al. (1995) studied multiple weed competition in corn and found that when red root pigweed was the dominant weed, yield was more affected by weed density than by weed distribution. Corn yield loss relative to weed density was linear. As weed density increased by one weed there was an 8.5 and 2.3 kg ha^{-1} corn yield loss in 1991 and 1992, respectively. Early weed emergence decreased crop yields more than late weed emergence. Vangessel and Renner (1990) studied red root pigweed and barnyard grass (*Echinochloa crus-galli* L.) in potatoes. Weeds seeded 6 to 7 weeks after potato planting did not affect yield. Weeds that emerged with the crop caused decreases in tuber yield. When red root pigweed emerged with the crop, one red root pigweed plant meter^{-1} row of potatoes reduced yield by 22 % to 33 %, depending on growing conditions. Knezevic et al. (1994) showed that the time of weed emergence was more critical to crop yield than the weed density. Corn yield losses ranged from 5 % to 34 % for pigweed densities of 0.5 to 8 plants m^{-1} row of corn, respectively, when the weeds emerged before the crop had reached the 4 th leaf stage (early weed emergence). When the weeds emerged between the 4 th and 7 th leaf stage of the crop, corn yield loss ranged from 5 % to 10 % for the same pigweed densities. After the 7th leaf stage (late weed emergence) of the crop, there was no measurable yield loss. Dieleman et al. (1995, 1996) studied green pigweed (*Amaranthus powellii* S.) and red root pigweed densities, and the time of weed emergence in soybeans to determine yield losses and develop economic models. Weeds emerging with the crop caused greater yield loss than weeds that emerged later in the growing season at a similar weed density. Soybean yield losses were estimated to decrease from 16.4 % to 0.5 % as weeds emerged later in the growing season. The time of emergence of pigweed in soybeans was more important than the weed density. The economic threshold increased as weeds emerge later in the growing season. If weeds emerged later in the growing season, a higher density was required in order to decrease crop yield.

Only a few studies have examined time of weed removal in canola (*Brassica napus* L. and *B. rapa* L.). Forcella (1987) and McMullen et al. (1994), studied time of weed removal in triazine-tolerant canolas. McMullen et al. (1994) showed that wild mustard (*Brassica kaber* [D.C] Wheeler var. *pinnatifida* [Stokes] Wheeler) decreased the yield of canola, and that the presence of wild mustard seed contaminated the canola oil by increasing the glucosinolate content. Canola yields were highest when wild mustard was removed at the earliest opportunity (McMullen et al. 1994). Forcella (1987) studied weed density thresholds to determine when it was economical to use a triazine-tolerant canola variety over a triazine-susceptible variety. He showed that 25 to 30 wild oat m^{-2} gave approximately a 17 % yield loss which was sufficient to warrant the use of the tolerant variety.

The introduction of herbicide-tolerant canola cultivars add to the options for weed control. However, herbicide-tolerant crops may cause producers to overlook other methods of weed control, or combinations of weed control methods. With the increase in farming inputs, environmental concerns, and the risk of resistant weeds developing, it is in the producer's best interest to look at all options for weed control to maximize economic returns.

In the current study, the effect of time of red root pigweed removal by herbicides on the yield of canola was studied at two sites in Alberta. Weed control was achieved using pre-plant incorporated (PPI) ethalfluralin and post-emergent glyphosate applications on glyphosate-tolerant canola. Competition effects of red root pigweed and natural weed infestations and times of herbicide applications were studied. The timing of red root pigweed removal was manipulated using PPI herbicides and post-emergent herbicides in sequence and alone. More specifically, does PPI ethalfluralin improve weed control with glyphosate, does one glyphosate application provide adequate weed control and does an early application of glyphosate increase yield compared to a late application of glyphosate?

3.2 Method and Materials

3.2.1 Locations

The experiment was conducted in 1996 and 1997 at the Alberta Environmental Center, Vegreville, AB., and at the Agriculture and Agri-Food Canada Research Station, Lacombe, AB. (Table 3.1). At each location, red root pigweed was seeded to achieve a constant distribution of the weed throughout the plot area, at either a high or low weed density. Weather records were retrieved from the weather stations at each location through Environment Canada and average weekly precipitation and air temperatures were recorded throughout the growing season for both years (Appendix 7.3).

Table 3.1 Site description for red root pigweed trials at Vegreville and Lacombe for 1996 and 1997.

Site and Year	**Vegreville 1996**	**Vegreville 1997**	**Lacombe 1996**	**Lacombe 1997**
Previous Cropping History	Fallow	Cereal Cover Crop	Fallow	Fallow
Soil Texture*	sandy loam - loam	sandy loam - loam	sandy clay loam	sandy clay loam
Sand	57 %	57 %	59 %	59 %
Silt	30 %	30 %	15 %	15 %
Clay	13 %	13 %	26 %	26 %
Organic Matter*	3.8 % - 6.8 %	3.8 % - 6.8 %	8 % - 9 %	8 % - 9 %
pH*	5.9 - 7.0	5.9 - 7.0	5.5 - 6.1	5.5 - 6.1

*based on top 15 cm of soil horizon

3.2.2 Experimental Design

The experimental design was a split, split randomized block design with six replications. The main plots were PPI herbicide treatments, the sub plots were weed densities and the sub, sub plots were post-emergent herbicide treatments and a hand-weeded check. The PPI treatments were either ethalfluralin or no ethalfluralin, the weed densities were either low or high red root pigweed density. The five treatments were post-emergent glyphosate applied as an early application, late application, an early and late application (double application of glyphosate applied at an early and late stage of canola), a control of no post-emergent herbicide application, and a hand-weeded check (Tables 3.2, 3.3, and 3.5).

3.2.3 Herbicide Application

Ethalfluralin (a 60 % active ingredient (a.i.) dispersible concentrate formulation) [N-ethyl-N-(2-methyl-2-propenyl)-2,6-dinitro-4-(trifluoromethyl) benzenamine] (w/w) was applied PPI at 1100 g a.i. ha^{-1} at Vegreville and at 1400 g a.i. ha^{-1} at Lacombe. Rates of ethalfluralin were calculated based on soil type, soil texture and organic matter (Tables 3.1, 3.2 and 3.3). Once the ethalfluralin was applied PPI in the spring, the area was disced twice to a depth of 10 to 12 cm, the first discing going length wise, and the second discing at right angles to the first.

Both the treated and untreated areas of ethalfluralin were disced with a tandom disc and the area then harrowed with diamond toothed harrows. The ethalfluralin was incorporated into the soil surface, and harrowed to smooth out the trial after discing. Liquid glyphosate [N-(phosphonomethyl)glycine] 356 grams liter^{-1} (g L^{-1}) acid equivalent (a.e.) was applied post-emergent. Glyphosate, a foliar applied, non-selective post emergent (POST) herbicide, was applied at 450 grams a.e. hectare^{-1} (ha^{-1}) or 0.5 L acre^{-1}. Glyphosate was applied at approximately the 2 to 3 leaf stage of canola (early glyphosate treatment) and at the 5 to 6 leaf stage of canola (late glyphosate treatment), but varied depending on weather conditions (Tables 3.2, and 3.3).

Table 3.2 Vegreville 1996 and 1997 spray information for red root pigweed trial.

Herbicide	**Pre-Plant Incorporated**		**Post-Emergent**					
Year	**1996**	**1997**	**1996**			**1997**		
Compound	Ethalfluralin (Edge® 60 DC)		Glyphosate (Roundup® 356 SL)					
Appl. Timing	Prior to Seeding		Early	Late	Early / Late	Early	Late	Early / Late
Canola leaf stage	-	-	3	6	3 / 6	2 - 3	6 - 7	2-3 / 6-7
Appl. Date	May-15	May-13	Jun-12	Jun-27	Jun-12 / 27	Jun-14	Jun-24	Jun-14/25
Rate of a. i. (g / ha)	1100	1100	450*	450*	450* / 450*	450*	450*	450* / 450*
Soil Temp °C[1]	7.0	10	-	-	-	16	19	16/19
Air Temp °C	-	15	20	7.5	20/7.5	20	20	20/20
% Humidity	-	-	25	98	25/98	78	95	78/95
Weather on spray day	snow/rain	sunny	sunny	foggy	sunny / foggy	sunny	cloudy	sunny / cloudy
Sprayer	Tractor CO_2	Tractor CO_2	Bicycle CO_2	Bicycle CO_2	Bicycle CO_2	Bicycle CO_2	Bicycle CO_2	Bicycle CO_2
Grnd Speed (km/hr)	7.3	7.3	4.0	4.0	4.0	4.0	4.0	4.0
H_2O Vol. (L ha^{-1})	131	131	110	110	110	110	110	110
Nozzle	8002	8002	11001	11001	11001	11001	11001	11001
# Nozzles	4	4	4	4	4	4	4	4
Screens	50	50	100	100	100	100	100	100
k Pa	278	278	278	278	278	278	278	278

*rate calculated using acid equivalent.

[1] temperature taken at a depth of 5 cm.

Table 3.3 Lacombe 1996 and 1997 spray information for red root pigweed trial.

Herbicide	**Pre-Plant Incorporated**		**Post-Emergent**					
Year	**1996**	**1997**	**1996**			**1997**		
Compound	Ethalfluralin (Edge® 60 DC)		Glyphosate (Roundup® 356 SL)					
Appl. Timing	Prior to Seeding		Early	Late	Early / Late	Early	Late	Early / Late
Canola leaf stage	-	-	3 - 3.5	5 - 6	3-3.5 / 5-6	2 - 3	5	2-3 / 5
Appl. Date	May-24	Apr-30	Jun-27	Jul-2	Jun-27 / Jul-2	Jun-7	Jun-16	Jun-7 / 16
Rate of a. i. (g / ha)	1100	1100	450*	450*	450* / 450*	450*	450*	450* / 450*
Soil Temp $^{o}C^{1}$	15	-	-	-	-	-	-	-
Air Temp ^{o}C	13	-	12	15	12 / 15	12	20	12 / 20
% Humidity	-	-	85	78	85 / 78	-	-	-
Weather	sunny	sunny	cloudy	sunny	cloudy / sunny	sunny	cloudy	sunny / cloudy
Sprayer	Tractor CO_2	Tractor CO_2	Small Plot CO_2	Small Plot CO_2	Small Plot CO_2	Small Plot CO_2	Small Plot CO_2	Small Plot CO_2
Grnd Spd (km/hr)			4.0	4.0	4.0	4.0	4.0	4.0
H_2O Vol. (L ha^{-1})	131	131	110	110	110	110	110	110
Nozzle	8002	8002	8001	8001	8001	8001	8001	8001
# Nozzles	4	4	4	4	4	4	4	4
Screens	50	50	100	100	100	100	100	100
k Pa	278	278	278	278	278	278	278	278

*rate calculated using acid equivalent.

[1] temperature taken at a depth of 5 cm.

3.2.4 Plant Establishment

The Round-up® tolerant canola cultivar 'Quest'® was used for both field seasons. 'Quest' is an Argentine canola (*Brassica napus* L.) variety which contains the Round-up Ready™ genes (Agriculture and Agri-Food Canada, 1995). The seed was treated with Vitavax®rs flowable which contains carbathiin, thiram and lindane. The red root pigweed seed was obtained from the Agriculture and Agri-Food Canada Research Station in Lacombe. Red root pigweed was hand-broadcasted onto the trial using small, hand-held shakers (Table 3.4), to achieve 50 seeds m^{-2} and 200 seeds m^{-2} for low and high weed densities, respectively, based on a 90% germination rate. Plots were then packed with a land packer to firm the seedbed and cover the small weed seeds, prior to seeding canola. Canola was cross-seeded at 6 kg ha^{-1} at a depth of 2.5 to 3.0 cm using a small-plot, double disc, press drill (Table 3.4). Weed counts were taken after canola emergence.

Table 3.4 Vegreville and Lacombe 1996 and 1997 summary for red root pigweed trial preparation.

Location	**Vegreville**				**Lacombe**			
Year	**1996**		**1997**		**1996**		**1997**	
Plant Seeded	RRP**	Canola	RRP**	Canola	RRP**	Canola	RRP**	Canola
Seeding Date								
Seeder	Hand shaker	double disc press drill	Hand shaker	double disc press drill	Hand Shaker	double disc press drill	Hand shaker	double disc press drill
Seeding Rate	50/200*	6 kg/ha	50/200*	6 kg/ha	50/200*	6 kg/ha	50/200*	6 kg/ha
Seeding Depth	surface	2.5 cm	surface	2.5 cm	surface	2.5 cm	surface	2.5 cm
Row Width	-	18 cm	-	18 cm	-	23 cm	-	23 cm
Fertilizer 12-51-00 banded	-	50 kg/ha	-	50 kg/ha	-	28 kg/ha	-	28 kg/ha
Desiccant ***	-	no	-	yes	-	no	-	yes

* low density seeded at 50 viable plants m^{-2} / high density seeded at 200 viable plants m $^{-2}$.

** RRP - Red root pigweed.

*** Reglone® used as desiccant prior to harvest.

Table 3.5 Vegreville and Lacombe 1996 and 1997 summary for red root pigweed hand-weeded treatments.

	Vegreville				**Lacombe**			
Year	**1996**		**1997**		**1996**		**1997**	
	1st Hand-weeding	2nd Hand-weeding	1st Hand-weeding	2nd Hand-weeding	1st Hand-weeding	2nd Hand-weeding	1st Hand-weeding	2nd Hand-weeding
Day	Jun-3	Jun-12	Jun-6	-	Jun-10	Jun-17	May-29	Jun-5
Canola leaf stage	1 leaf	-	cotyledon - 1 leaf	-	cotyledon - 1 leaf		cotyledon	-
Weed leaf stage	cotyledon	-	cotyledon - 1 leaf	-	cotyledon	-	cotyledon	-

3.2 5 Data Collection

Weed survival was assessed visually approximately 2 weeks after the last application of glyphosate. The rating was based on % of weed biomass remaining in each treatment compared to the untreated controls - 100 % representing complete weed control, 0 % representing no weed control. Canola was harvested with a small plot combine from 7.4 m by 1.4 m plots in Lacombe and 8.0 m by 1.2 m plots in Vegreville. Plots were harvested at seed maturity in early to late September. In 1996, each harvested sample was dried to 5.5 % to 6.5 % moisture level, cleaned with sieves and weighed. In 1997, a weigh unit on the small plot combine was used to measure yield and % moisture from each treatment at time of harvest. Sub samples were collected and used to determine dockage. Dockage was only found in sub-samples of plots that had not received an application of herbicide. Dockage ranged from 7 % to 20 %.

3.2.6 Data Analysis

Analysis of variance was performed on all parameters using SAS General Linear Model (GLM) procedure to determine significant interactions (SAS Institute Inc. 1996). The probabilities of differences between means were calculated using PDIFF option of the LSMEANS procedure. All means were compared at ($P<0.05$) level.

3.3 Results and Discussion

At Lacombe and Vegreville in 1996 and 1997, red root pigweed and other broadleaf weed species emerged simultaneously with the canola or shortly after canola emergence. All weed populations were recorded at the time of second glyphosate application (Tables 7.2.20 and 7.2.23). Both field seasons in Lacombe had relatively poor red root pigweed emergence and growth, even though red root pigweed densities were high enough for competitive affects to occur between weed and crop, according to previous studies (Dieleman et al., 1996; Knezevic et al., 1994; Swinton et al., 1994). At Lacombe in 1996 and 1997, the canola grew quickly, closing its leaf canopy over the red root pigweed. Lamb's quarters and stinkweed (*Thlaspi arvense* L.) were two weeds present throughout the trials at Lacombe and Vegreville (Tables 7.2.20 and 7.2.23). In 1996, at Vegreville, populations of smart weed (*Polygonum scabrum* Moench) grew with the canola (Table 7.2.22). When present, lamb's quarters expanded above the canola canopy, whereas stinkweed grew with the canola.

Past research has suggested that C4 plant species were more competitive than C3 plant species when moisture was limited and temperatures were high (Patterson and Flint, 1983; Ozturk et al., 1981; Wiese and Vandiver, 1970). Weaver (1984) showed that the competitiveness of red root pigweed decreased in cooler greenhouse conditions. Weather and growing conditions at Lacombe and Vegreville may be more favorable for canola growth than pigweed growth.

Weekly precipitation and temperatures for both years were recorded (Tables 7.3.3 to 7.3.6). Monthly precipitation and temperature means for location (40 year (plus) averages) and for the 1996 and 1997 growing seasons are plotted together (Figures 7.3.1 to 7.3.4). The temperatures at Lacombe and Vegreville for 1996 and 1997 were slightly below the 40 year average. Temperatures for 1997 were cooler in April at both locations and then increased to approximately the 40 year average. Temperature means for the two field seasons were higher in Vegreville than in Lacombe (Figures 7.3.5 to 7.3.8). In 1997, Vegreville did not become warmer than Lacombe until after the last week of April, then temperatures were generally warmer in Vegreville throughout the remainder of the growing season.

The precipitation at both locations was generally above the 40 year averages (Figures 7.3.2 and 7.3.4). There was more precipitation in the 1996 than in the

1997 growing season. On average, Lacombe received more precipitation than Vegreville (Figure 2.1). In 1996, by the end of May, Lacombe had received 148 mm and Vegreville 62 mm of rain. By the end of July, 1996, Lacombe had received 380 mm and Vegreville 224 mm of rain. By the end of May, 1997, Lacombe had received 78 mm and Vegreville 91 mm of rain; however, by the end of July Lacombe had received 267 mm and Vegreville 239 mm of rain.

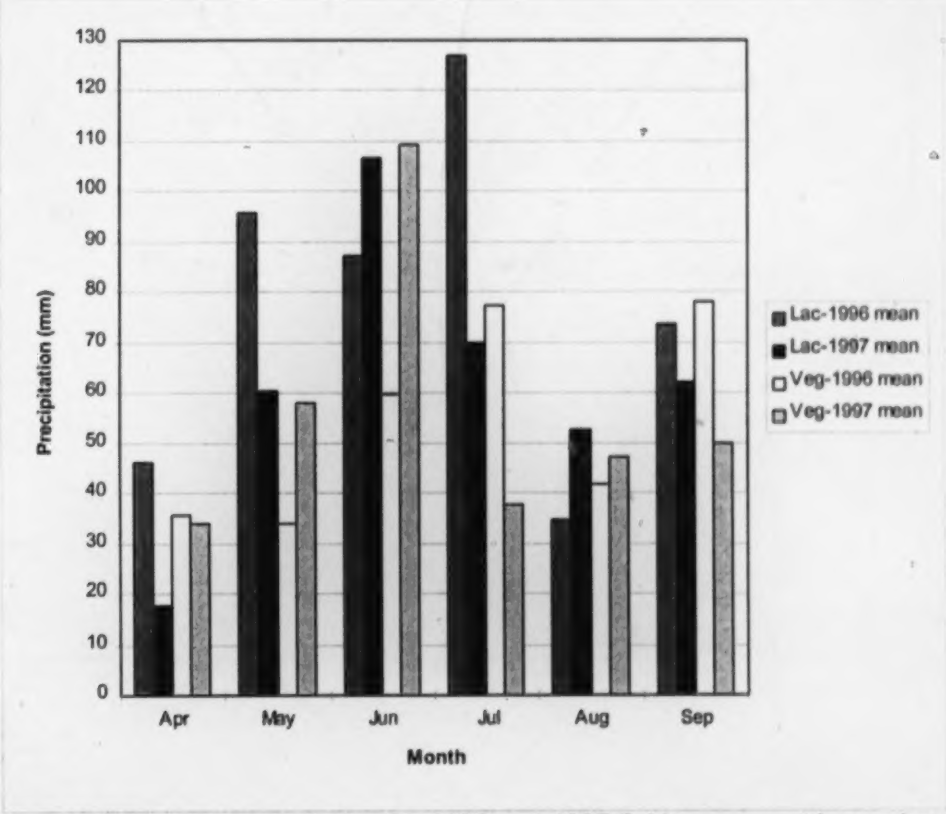

Figure 3.1 Monthly precipitation for 1996 and 1997 field seasons at Lacombe and Vegreville.

Yields were higher in Vegreville than Lacombe (Table 7.2.2), even though Vegreville had drier growing conditions and received less precipitation than Lacombe. (Tables 7.3.3 to 7.3.6). Plots in Vegreville had increased spacing between individual treatments, due to the type of sprayer used. The low weed populations allowed the canola to expand into the area between the plots which may have increased yield. Late applications of glyphosate, either alone, or after an early application of glyphosate, caused discoloration of the canola leaves and delayed flowering. This response was more noticeable at Lacombe. The lighter yellow flowers could have been due to a delay in flowering or a discoloration of the flowers.

Trial (site by year) interacted with various treatments; therefore, each trial was analyzed separately (Table 7.2.1). The analysis of variance for canola yield showed a number of significant main effects and interactions. These interactions occurred due to the weedy-check and the hand-weeded treatment. The glyphosate treatments were analyzed separately from the weedy-check and the hand-weeded treatments (Table 3.6). Trial by treatment was not significant (P=0.19) therefore, all trials were analyzed together (Table 3.6). Treatment was the only significant variable (P=0.02) and contrasts were made between the glyphosate treatments (Table 3.7).

Table 3.6 Summary of analysis of variance for canola yield from plots treated with glyphosate for 1996 and 1997 field seasons at Lacombe and Vegreville.

Source	Prob.
Trial (T)	0.0001
Rep (Trial)	--
PPI Herbicide (H)	0.48
H x T	0.60
Error 1	--
Density (D)	0.25
D x T	0.74
D x H	0.68
D x H x T	0.78
Error 2	--
Treatment (Tr)	0.02
Tr x T	0.19
Tr x H	0.33
Tr x H x T	0.70
Tr x D	0.07
Tr x D x T	0.97
Tr x D x H	0.24
Tr x D x H x T	0.98
Error 3	--

Table 3.7 The effect of time of glyphosate application on canola yield analyzed across four trials (Lacombe 1996, Lacombe 1997, Vegreville 1996 and Vegreville 1997).

Treatment		**Trial**
Number	**Herbicide**	**Yield (kg ha^{-1})**
1	E glyph	4408
2	E / L glyph	4257
3	L glyph	4283
	standard error	**41**
Contrasts		**Pr**
	1 vs 2	0.01
	1 vs 3	0.04
	2 vs 3	0.66

E glyph = early application of glyphosate. L glyph = late application of glyphosate. E / L glyph = early and late applications of glyphosate.

The timing and number of glyphosate applications significantly affected canola yield (Table 3.7). The highest canola yield was harvested from plots that had received the early application of glyphosate (4408 kg ha^{-1}) (Table 3.7). This yield was significantly higher than canola yield from plots that had received the early / late application of glyphosate (P=0.01), the late application of glyphosate (P=0.04) (Table 3.7) and no application of glyphosate (4051 kg ha^{-1}) (Table 7.2.9). There was no difference in yield between the double and late applications of glyphosate (P=0.66) (Table 3.7). Red root pigweed density did not affect canola yield when glyphosate was applied. The application of ethalfluralin prior to glyphosate did not have a significant effect on canola yield (P=0.48) (Table 3.6).

Glyphosate provided excellent weed control and when applied early, early weed removal. The early application of glyphosate significantly increased canola yield compared to the late application of glyphosate. Past research has shown that early application of post-emergent herbicides will remove weeds early, increase weed control and yield (Kirkland, 1995). The application of PPI ethalfluralin prior to glyphosate did not increase canola yield. In other crops, the use of sequential applications of PPI herbicides and post-emergent herbicides has increased yield when a second flush of weeds occurred (Jordan et al., 1993). A model created by Berti et al. (1996) that focused on two weeds in corn and soybeans showed that PPI or pre-emergent herbicides followed by the application of two post-emergent herbicides, significantly increased yield when high weed pressures were present in the crop.

3.4 Conclusions

1. The effective weed control from an early application of glyphosate, significantly increased canola yield when compared to harvested canola yield from plots that had received an early / late application or a late application of glyphosate.

2. The early / late application of glyphosate decreased the advantage of the early glyphosate application due to crop injury.
3. When weeds were successfully controlled by herbicide application early in the crop life cycle, there was no significant difference in crop yield response between the high and low weed densities.

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Chapter 4 Wild Oat (*Avena fatua*) and Red Root Pigweed (*Amaranthus retroflexus*) Competition with Canola Under Greenhouse Conditions.

4.1 Introduction

When an undesired plant species is growing with a desired plant species, the undesired species is usually considered a weed. Since early agriculture, farmers have had to deal with undesirable plants interfering with crop plants. The amount of weed interference with the crop depends on the available resources and conditions for plant grown. Plants compete for the environmental resources (moisture, light and nutrients) that are often in limited supply but are required to maximize plant growth in the growing season (Fabricius and Nalewaja, 1968; Harris and Ritter, 1987; Kramer, 1980; Patterson and Highsmith, 1989; Stoller and Myers, 1989; Stoller and Woolley, 1985). Environmental conditions (temperature and soil pH) also influence the amount of growth plants achieve in a growing season (Buchanan et al., 1975; Patterson, 1982). Environmental conditions and resources are factors that are highly variable and will affect crop growth differently each growing season.

Weedy species compete with the crop, using a portion of the limited environmental resources, making the resource unavailable to the crop plant. When two species are competing with each other, inter-specific competition occurs. When one of the species is removed inter-specific competition is eliminated and intra-specific competition, or competition that occurs between plants of a single species occurs (Morishita et al., 1991; O'Donovan and Blackshaw, 1997; Shrefler et al., 1994). The competitive ability of plants can be influenced by the time of plant emergence and their ability to obtain limiting resources (Spitters and van den Bergh, 1982). Competitive weeds are able to out-compete crops for resources and cause decreases in yield due to inter-specific competition (Ghosheh et al., 1996; O'Donovan and Blackshaw, 1997; Shrefler et al., 1994).

Moisture levels have been shown to cause changes in crop growth and yield production. Low levels of available water can permit some weedy species to become more competitive with the crop, reducing crop growth (Ball and Shaffer, 1993; Hagood et al., 1980). When moisture is not limiting, the critical weed density is generally higher in order to have the same competitive effect on the crop. This results in an increase in intra-specific competition between the weed species and an increase in inter-specific competition between the weed and the crop (Vangessel et al., 1995). The opposite interaction can also occur as weed species that are competitive in moist conditions become less competitive in drought conditions (Wiese and Vandiver, 1970). Therefore, when plants become stressed from limited resources, it is important to know the length of time that weeds can compete with the crop without affecting yield, or the time period in which weeds must be controlled to prevent yield loss from the crop, the critical weed-free period (Weaver and Tan, 1983; Zimdahl, 1988).

Critical weed-free periods vary with the weed, crop and environmental conditions. Under dry conditions, the critical weed-free period can increase, making early weed removal more important (Jackson et al., 1985; Coble et al., 1981). Some weeds are more competitive under dry conditions, effecting yield loss when moisture is limiting (Harrison et al., 1985). C-4 plant species are generally more competitive than C-3 plant species when moisture is limited and temperatures are high (Patterson and Flint, 1983; Ozturk et al., 1981; Wiese and Vandiver, 1970). Red root pigweed (*Amaranthus retroflexus* L.) is an annual, C-4 broadleaf weed that has been shown to be more competitive under dry conditions than oats (*Avena sativa* L.), an annual C-3 grass (Ozturk et al., 1981). Ozturk et al., (1981) showed that C-4 species were generally more productive when drought stressed, and less productive when under moist conditions, when compared with C-3 species. Orwick and Schreiber (1979) studied red root pigweed in soybeans and found that as soil moisture decreased, red root pigweed became more competitive. Changes in moisture availability affect weeds and crops differently throughout the growing season. In certain crops, water stress later in the growing season can decrease crop yield more than water stress early in the growing season (Eaton et al., 1973; Eaton et al., 1976). It is important to remove weeds prior to the time when the weed can be the most competitive and damaging to crop yield.

A second environmental factor that affects plant growth is light. Some weeds are able to extend above the crop canopy and shade the crop, increasing inter-specific competition. Stoller and Woolley (1985) showed that soybeans lost 19 % to 25 % yield, when shaded from 44 % to 56 %, respectively, by weeds with no other limiting resources. Due to the negative effect shading has on crops (Stoller and Myers, 1989; Stoller and Woolley, 1985; Patterson, 1982), models have been developed to predict yield loss by measuring weed leaf area (Vitta and Quintanilla, 1996). A shaded plant may increase biomass partitioning to leaves (Patterson, 1982), have lower root / shoot ratios and decreased ability to compete for moisture (Stoller and Myers, 1989). If crop plants are shaded early in the growing season, their ability to compete for moisture later on in the season, if moisture becomes limiting, will be less than if they had not been shaded. However, when plants are moisture stressed, growth and competition for light may be reduced (Patterson, 1995). To compensate for the reduced light, some plants will decrease leaf thickness and increase chlorophyll content per unit leaf area, increasing photosynthetic rate per unit leaf area (Regnier et al., 1988). A review by Patterson, (1995) showed that competing weeds and crop plants generally respond the same way to shading.

Temperature can also affect weed-crop competition. Anderson and Nielsen (1996) studied temperature thresholds for seedling emergence of five weed species. They determined daily temperature fluctuations seven days prior to weed emergence. Weed species included in the study were green foxtail (*Setaria viridis* L.), kochia (*Kochia scoparia* L.), red root pigweed, volunteer wheat (*Triticum aestivum* L.), and wild-proso millet (*Panicum miliaceum* L.). Minimum and maximum temperatures that were reached prior to red root pigweed emergence were 8.5 to 9.5 °C and 22.2 to 25 °C, respectively. The time for emergence ranged from approximately May 30 to Aug. 22. Patterson and Flint (1983) studied temperature effects on soybean growth with cocklebur (*Xanthium pensylvanicum* Wallr.), and smooth pigweed (*Amaranthus hybridus* L.). Smooth pigweed, a C-4 broadleaf, was most competitive at higher temperatures. This showed that pigweed could be more of a problem in late planted soybeans or possibly other late planted crops. Early seeding can be important to allow the crop to establish before any late emerging weeds. Allowing the crop to form a canopy and an extensive root system, increases the competitive ability of the crop.

Wild oat is a large seeded, C-3, annual grass weed, and red root pigweed is a small seeded, C-4, annual broadleaf weed. Both weeds are considered a problem in some areas. However, both weeds may not be a problem in the same field since red root pigweed is more competitive in areas that have dry, warm growing conditions such as south-western Ontario and the corn-soybean belt in the United States (Anderson and Nielsen, 1996, Flint and Patterson, 1983, Frick and Thomas, 1992; Potter and Jones, 1977). Wild oat is more competitive in areas that have moist, cool growing conditions such as western Canada (Thomas, 1985).

Canola (*Brassica napus* L. and *B. rapa*) is a major oilseed crop grown throughout western Canada. Canola's competitive ability as a crop varies when compared to other crops, and depends on the weeds present. When wild oat is present, canola is less competitive than barley but is similar to wheat (Dew, 1972; Dew and Keys, 1976; O'Donovan, 1988). Canola is more competitive than peas and flax when competing with wild oat (Friesen et al., 1990; Marshall et al., 1989). O'Donovan and Blackshaw (1997) showed volunteer barley densities of 5 to 20 plants m^{-2} reduced pea yields 8 to 27 %, respectively, whereas a study done by O'Donovan et al. (1988) suggested canola yield loss was less for similar volunteer barley densities.

The objective of this study was to characterize the competitive ability of canola with wild oat and red root pigweed at two moisture regimes, two weed densities, and three times of weed removal. More specifically, does early weed removal from canola under drought conditions affect canola growth more than early weed removal in non-drought conditions, and what changes occur with increased weed density?

4.2 Method and Materials

4.2.1 Introduction

The experiments were conducted at the University of Alberta, in the Agricultural, Food and Nutritional Science greenhouses between January 24 and April 4, 1997. Two separate greenhouse experiments were initiated (Table 4.1). One experiment involved the competitive effects of red root pigweed with canola and a second experiment involved the competitive effects of wild oat with canola under controlled moisture regimes and weed densities.

Table 4.1 Greenhouse summary for canola and weed seeding date, seeding depths and time weeds were removed from the canola.

	Red Root Pigweed Trial	**Wild Oat Trial**
Canola Seeded	Jan-24	Mar-10
Seed Depth (cm)	2 - 2.5	1
Weed Seeded	Jan-24	Mar-7
Seed Depth (cm)	0.25 - 0.5	3
Weed Removal (1st)	Feb-14	Mar-28
Canola Stage	3 leaf	3 leaf
Weed Removal (2nd)	Feb-26	Apr-4
Canola Stage	6 leaf	5 - 6 leaf

4.2.2 Experimental Design

The experimental design for both competition experiments was a randomized block design with four blocks. Treatments included high and low densities of red root pigweed and wild oat, moisture regimes of field capacity (FC) and 1/4 FC, and times of weed removal at the 2 to 3 leaf stage, and at the 5 leaf stage to bolting of the canola. Weed seeds were not planted in the control treatments.

4.2.3 Greenhouse Climate

The greenhouse was set at 21 °C day and 18 °C night temperatures for both studies. Photoperiod was 16 hours supplemented with high intensity discharge (HID) lighting from 400 watt, high pressure, sodium lamps. Light irradiance was 420 to 430 $\mu E\ m^{-2} s^{-1}$ at the soil surface, measured using a LI - COR (LI - 188) Integrating Quantum / Radiometer / Photometer.

4.2.4 Greenhouse Preparation

The pots used in both experiments had a 25 cm diameter. Each pot was weighed and then tarred, and a weighed amount of soil-less medium was added to each pot and the weight recorded. The soil-less mixture included approximately 1:1:1/3 of peat:vermiculite:medium sand, by volume (Stringam, 1971). The following nutrients were added to every 36 L of the soil mix: 270 g of dolomitic lime, 140 g of super phosphate (0-45-0), 240 g of 14-14-14, 2 g of iron chelate and 4 g of chelated trace elements (copper, zinc and iron). The peat and sand were autoclaved for 1 hour prior to soil mixing and use . Vermiculite was not autoclaved due to the possibility of toxicity problems. After autoclaving, the peat, sand, vermiculite, and nutrients were mixed together in a soil mixer and then transferred to the pots. Sub samples were removed from the mixture when pots were filled. These samples were dried at approximately 75 °C for 72 hours and then weighed to determine moisture content at time of filling the pots. Measuring moisture content of the soil allowed for calculation of the two soil water capacities.

4.2.5 Water Potential

Soil water potential was measured using a pressure plate method which allowed the determination of the moisture characteristic curve of the soil (Hillel, 1982). Pressures used were 15 bars, 1 bar, 0.33 bar and 0.1 bar. The measurements were repeated twice (Appendix 7.4.1). A soil wetting curve was constructed and the unavailable, available, and gravitational water determined. FC and 1/4 FC were then determined from the part of curve that represented available water.

4.2.6 Seeding

Seeding was done using a cardboard template (Figure 4.1). The canola was placed into two rows with four canola plants per row and then weeds were placed in rows, between the canola, on the outside of the canola rows, and as single plants at the ends of the canola rows. A template allowed for a systematic approach to seeding the greenhouse experiment. The canola seeded was cultivar 'Quest'®. This planting pattern represented a canola seeding rate of approximately 6 kg ha^{-1} and weed densities were approximately 315 plants m^{-2} and 79 plants m^{-2} for high and low weed densities, respectively.

Three canola seeds, four red root pigweed seeds or three wild oat seeds were seeded at each position. Multiple plants allowed for thinning at the cotyledon stage and guaranteed eight canola plants and proper weed densities per pot. No Damp® was applied to all pots in both experiments to prevent pre- and post-emergent damping off pathogens from killing the seedlings. All pots were kept at field capacity by daily watering to weight, until all seedlings had emerged and then the pots were allowed to dry down to the required moisture contents. Moisture regimes were maintained by weighing each pot two times a day and adding water as required. Table 4.1 outlines time of seeding, and time of weed removal. Canola was harvested at the late time of weed removal treatment.

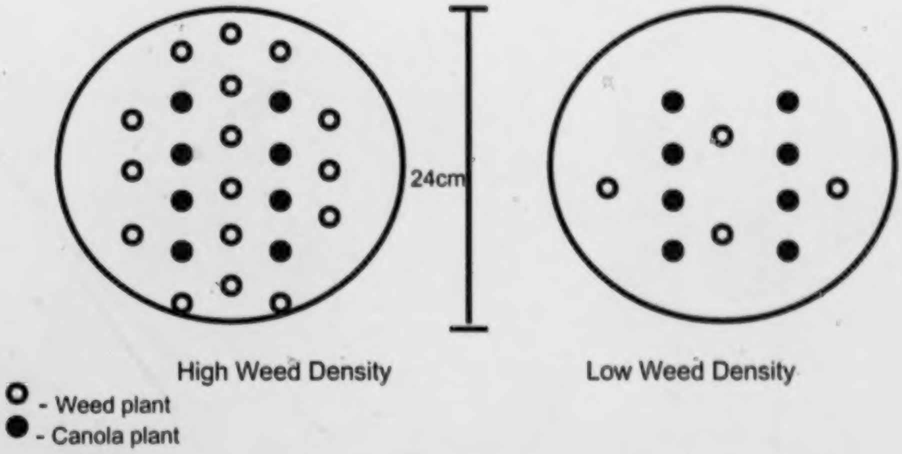

Figure 4.1 Cardboard templates used for seeding canola and high and low weed densities.

4.2.7 Weed Removal and Harvest

Weeds were removed by hand at the 3 leaf stage of the canola and at harvest stage of the canola (Table 4.1). The control had no weeds seeded in with the canola and the canola was harvested at approximately the 5 leaf to bud stage of the canola. Leaf area and leaf number per canola plant were recorded at harvest. Leaf area was measured using a LI - COR (LI - 3100) area meter. Leaves and stems were separated and dried for 72 hours at 75 °C. Leaf and stem weights were then recorded and total above ground plant weight (shoot weight), and leaf weight ratio [leaf dry weight / shoot dry weight (g/g)] were calculated. Weed biomass, weed leaf numbers and leaf area were also recorded. Previous field research has shown that at approximately 40 days of weed-rapeseed competition, significant decreases in canola biomass have resulted in significant yield reductions (Blackshaw et al., 1987; Forcella, 1987; Marshall et al., 1989).

4.2.8 Data Analysis

Analysis of variance was performed on all parameters measured using SAS (SAS Institute Inc. 1996) General Linear Model (GLM) procedure to determine significant interactions. The probabilities of differences between means were calculated using PDIFF option of the LSMEANS procedure. All means were compared at ($P<0.05$) level.

4.3 Results and Discussion

4.3.1 Wild Oat Greenhouse Trial

Analysis of variance indicated a number of significant main treatment effects and interactions (Table 4.2). Increased time of weed competition, decreased moisture level and increased wild oat density all significantly decreased canola growth parameters. A significant two way interaction occurred between time of wild oat removal x moisture (RxM) for leaf area, leaf weight, stem weight, and shoot weight (total above ground plant weight). A significant two way interaction occurred between time of wild oat removal x wild oat density (RxD) for leaf area, leaf number, leaf weight, shoot weight (total above ground plant weight), and leaf weight ratio (g/g). A significant two way interaction occurred between moisture x wild oat density (MxD) for shoot weight and stem weight.

Table 4.2 Summary of analysis of variance for canola growth parameters from the greenhouse wild oat competition trial.

	Pr > F for Canola Growth Parameters					
Source	**leaf area (cm^2)**	**leaf #**	**leaf wt (g)**	**stem wt (g)**	**shoot wt (g)**	**leaf weight ratio (g/g)**
Removal	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Moisture	0.0001	0.48	0.0001	0.0001	0.0001	0.0001
R x M	0.02	0.31	0.012	0.015	0.004	0.44
Density	0.0001	0.0001	0.0001	0.0001	0.0001	0.08
R x D	0.0006	0.01	0.0001	0.13	0.0006	0.002
M x D	0.23	0.73	0.084	0.05	0.03	0.95
RxMxD	0.34	0.29	0.26	0.98	0.62	0.49

Wild oat and canola emerged together. Visual and measurable differences in canola leaf size were observed at the time of early weed removal of wild oat (Table 7.4.3). At the late time of wild oat removal, and harvest of canola (April 4), canola was approximately at the 5 leaf to bud stage, except in the 1/4 FC by high wild oat density treatment, where the canola was at the 4 leaf to bud stage (Table 7.4.3).

Moisture Effects on Time of Wild Oat Removal

The interaction, wild oat removal by moisture regime, showed that high moisture was not able to compensate for later weed removal (Figures 4.2, 4.3, 4.4 and 4.5). It was important to remove the weeds early whether plants were moisture stressed or not. Field research by Mortensen and Coble (1989) showed that common cocklebur decreased soybean yield 29 % and 12 % in well watered and drought stressed growing conditions, respectively. When canola was grown at FC, extended wild oat competition had a greater effect on canola growth parameters than when wild oat was removed early.

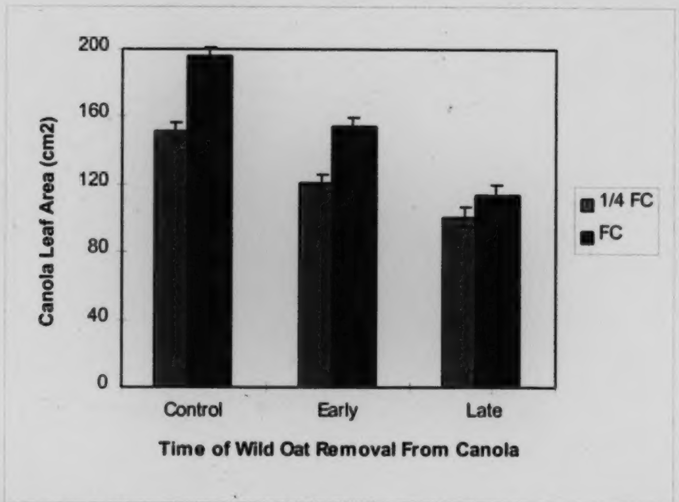

Figure 4.2 Wild oat removal by moisture regime for canola leaf area (cm^2). Weeds were removed at 2-3 leaf (Early), and 5-6 leaf (Late) stage of canola. Moisture regimes were at 1/4 field capacity (1/4FC) and field capacity (FC). Means were averaged over high and low wild oat densities. Standard error of the means was 5.3 cm^2.

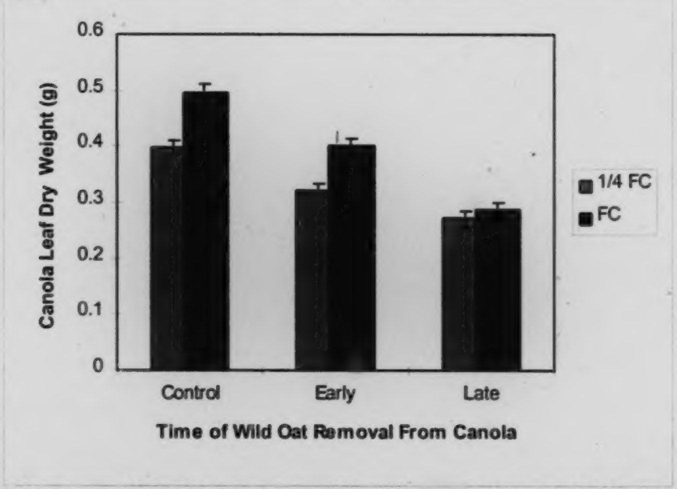

Figure 4.3 Wild oat removal by moisture regime for canola leaf dry weight (g). Weeds were removed at 2-3 leaf (Early), and 5-6 leaf (Late) stage of canola. Moisture regimes were at 1/4 field capacity (1/4FC) and field capacity (FC). Means were averaged over high and low wild oat densities. Standard error of the means was 0.013 g.

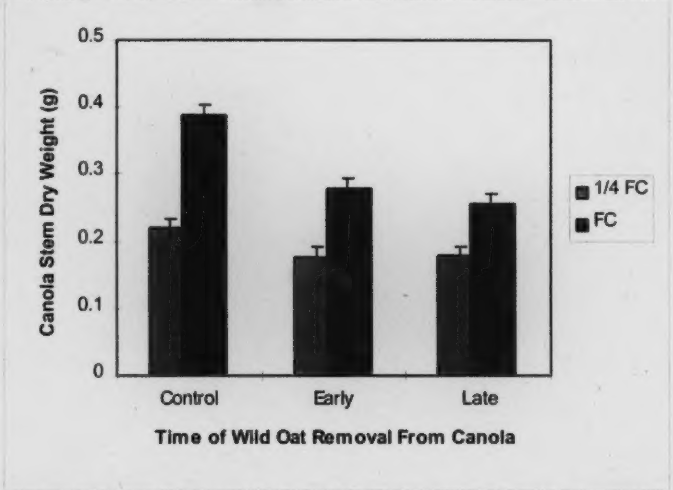

Figure 4.4 Wild oat removal by moisture regime for canola stem dry weight (g). Weeds were removed at 2-3 leaf (Early), and 5-6 leaf (Late) stage of canola. Moisture regimes were at 1/4 field capacity (1/4FC) and field capacity (FC). Means were averaged over high and low wild oat densities. Standard error of the means was 0.015 g.

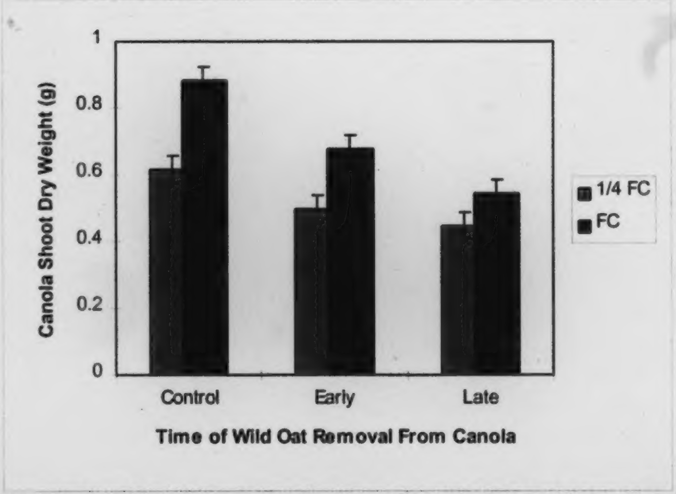

Figure 4.5 Wild oat removal by moisture regime for canola shoot dry weight (g). Weeds were removed at 2-3 leaf (Early), and 5-6 leaf (Late) stage of canola. Moisture regimes were at 1/4 field capacity (1/4FC) and field capacity (FC). Means were averaged over high and low wild oat densities. Standard error of the means was 0.024 g.

Density Effects on Time of Wild Oat Removal.

The interaction, wild oat removal by wild oat density, showed that canola growth parameters decreased more rapidly with later weed removal at the high wild oat density than at the low wild oat density (Figures 4.6, 4.7, 4.8 and 4.9). Cudney et al. (1989) showed a significant linear decrease in grain yield of wheat as wild oat density increased, and Crook and Renner (1990) showed that yield increased the earlier high weed densities were removed from the crop. As removal times of weeds were delayed, higher weed densities generally resulted in lower yields than lower weed densities. It was more important to remove the high wild oat density than low wild oat density as early as possible to increase canola growth parameters at the time of harvest.

Canola leaf weight ratio (Figure 4.10) decreased from the early time of wild oat removal to the late time of wild oat removal. High and low wild oat densities did not have a significant effect on canola leaf weight ratio.

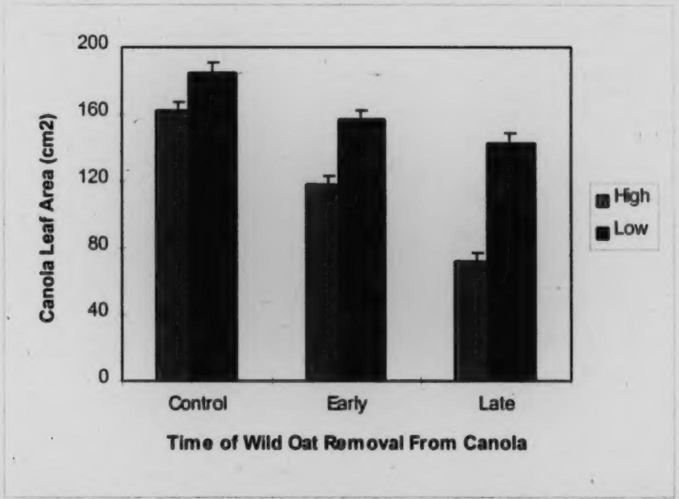

Figure 4.6 Wild oat removal by wild oat density for canola leaf area (cm^2). Weeds were removed at 2-3 leaf (Early), and 5-6 leaf (Late) stage of canola. Wild oat was seeded at high and low weed densities. Means were averaged over 1/4 field capacity and field capacity moisture regimes. Standard error of the means was 5.3 cm^2.

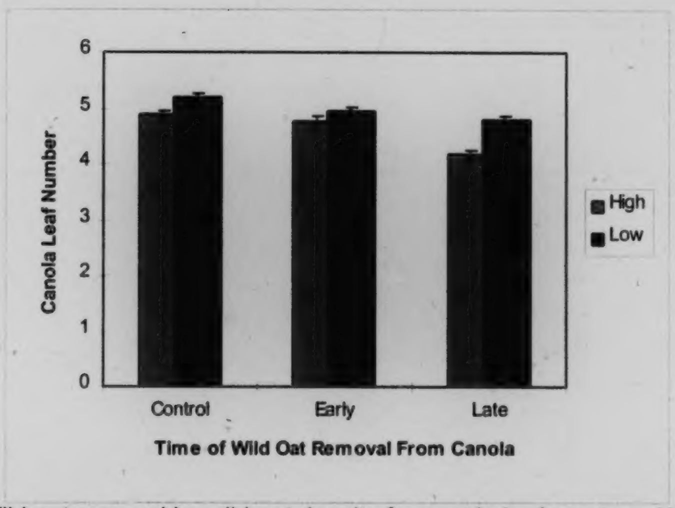

Figure 4.7 Wild oat removal by wild oat density for canola leaf number. Weeds were removed at 2-3 leaf (Early), and 5-6 leaf (Late) stage of canola. Wild oat was seeded at high and low weed densities. Means were averaged over 1/4 field capacity and field capacity moisture regimes. Standard error of the means was 0.07g.

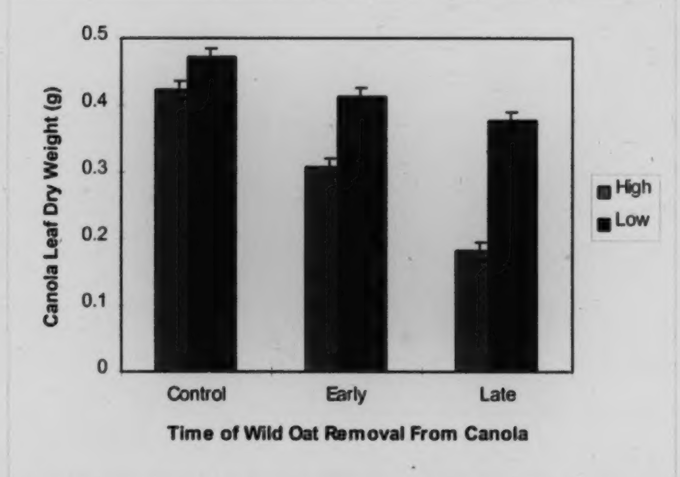

Figure 4.8 Wild oat removal by wild oat density for canola leaf dry weight (g). Weeds were removed at 2-3 leaf (Early), and 5-6 leaf (Late) stage of canola. Wild oat was seeded at high and low weed densities. Means were averaged over 1/4 field capacity and field capacity moisture regimes. Standard error of the means was 0.01g.

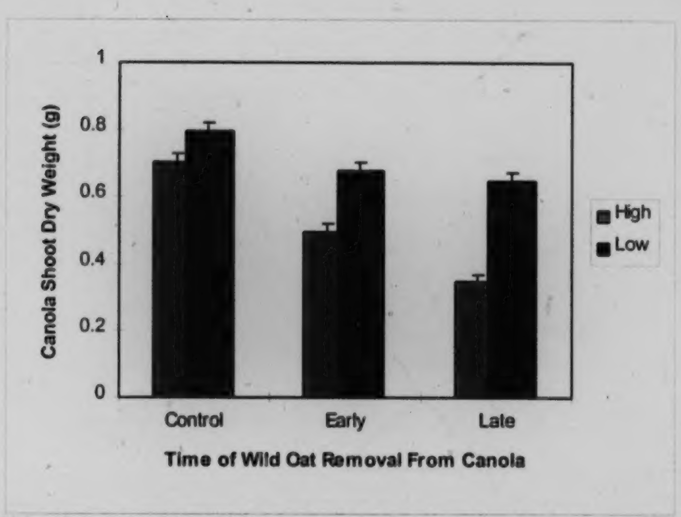

Figure 4.9 Wild oat removal by wild oat density for canola shoot dry weight (g). Weeds were removed at 2-3 leaf (Early), and 5-6 leaf (Late) stage of canola. Wild oat was seeded at high and low weed densities. Means were averaged over 1/4 field capacity and field capacity moisture regimes. Standard error of the means was 0.015g.

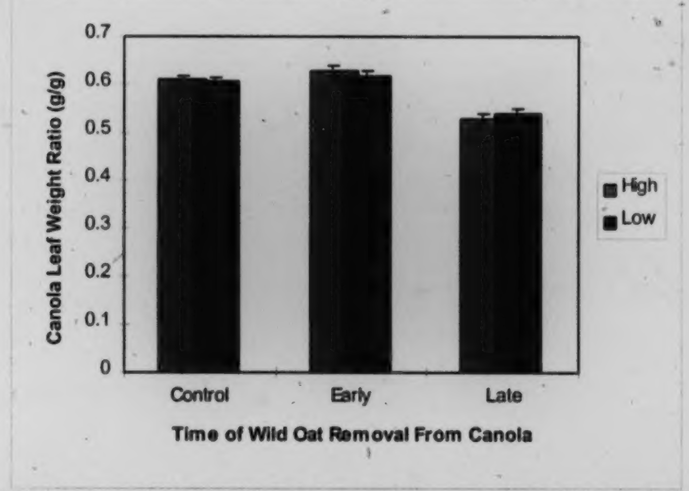

Figure 4.10 Wild oat removal by wild oat density for canola leaf dry weight ratio (g/g). Weeds were removed at 2-3 leaf (Early), and 5-6 leaf (Late) stage of canola. Wild oat was seeded at high and low weed densities. Means were averaged over 1/4 field capacity and field capacity moisture regimes. Standard error of the means was 0.024g.

Moisture Effects on High and Low Wild Oat Densities.

The two way interaction, weed density by moisture regime, showed moisture had a greater effect on canola growth parameters at the low wild oat density compared to the high wild oat density (Figure 4.11 and 4.12). At FC, there was a greater difference between high and low wild oat density than at 1/4 FC.

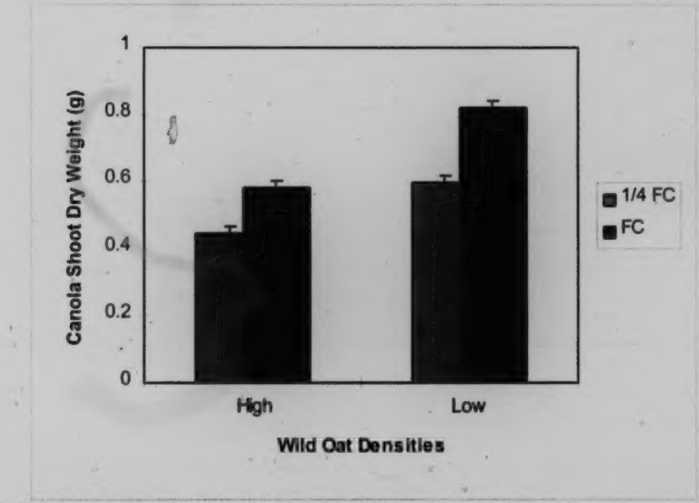

Figure 4.11 Wild oat density by moisture regime for canola shoot dry weight (g). Wild oat was seeded at high and low densities. Moister regimes were 1/4 field capacity (1/4 FC) and field capacity (FC). Means were averaged over three times of wild oat removal. Standard error of the means was 0.02 g.

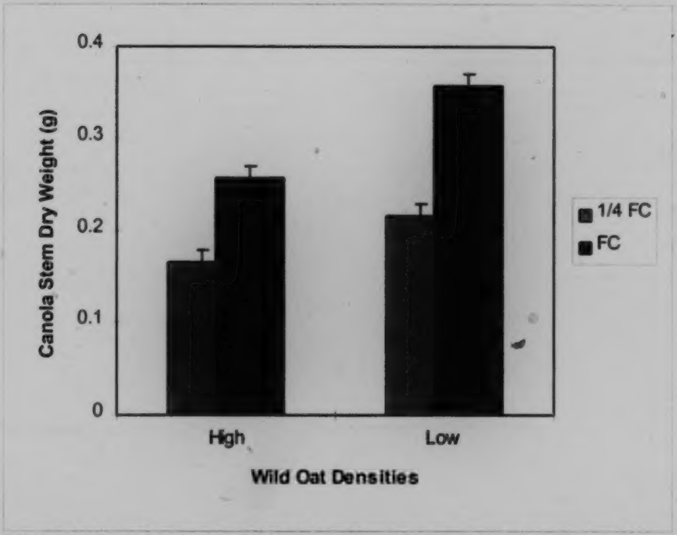

Figure 4.12 Wild oat density by moisture regime for canola stem dry weight (g). Wild oat was seeded at high and low densities. Moister regimes were 1/4 field capacity (1/4 FC) and field capacity (FC). Means were averaged over three times of wild oat removal. Standard error of the means was 0.013 g.

4.3.2 Red Root Pigweed Greenhouse Trial.

Analysis of variance of canola growth parameters indicated two significant main treatment effects, time of red root pigweed removal (Removal) and moisture regime (Moisture) (Table 4.3). In the experiment, there appeared to be little difference in competitive interference from among the red root pigweed densities (Tables 4.3 and 7.4.2). There were no significant interactions (Table 4.3).

Table 4.3 Summary of analysis of variance for canola growth parameters from the greenhouse red root pigweed competition trial.

	Pr > F for Canola Growth Parameters					
Source	**leaf area (cm^2)**	**leaf #**	**leaf wt (g)**	**stem wt (g)**	**shoot wt (g)**	**leaf weight ratio (g/g)**
Removal	0.16	0.42	0.20	0.1	0.53	0.0018
Moisture	0.0001	0.06	0.0001	0.0004	0.0001	0.0009
R x M	0.51	0.48	0.30	0.50	0.34	0.55
Density	0.86	0.46	0.47	0.95	0.59	0.37
R x D	0.93	0.12	0.99	0.19	0.79	0.24
M x D	0.72	0.21	0.46	0.50	0.43	0.95
RxMxD	0.86	0.39	0.99	0.43	0.93	0.32

Red root pigweed emerged at the same time as the canola, but grew slowly compared to the canola. The canola shaded the red root pigweed. The red root pigweed height remained low and under the canola leaf canopy throughout the duration of the experiment. However, the pigweed began to mature early. Leaf number of red root pigweed was highly variable at each time of weed removal (Table 7.4.2). The leaf number of the canola remained consistent at each time of weed removal and at both soil moisture regimes (Table 7.4.2). The greenhouse conditions of 21 °C / 18 °C (day / night) temperatures were probably more suitable for canola than red root pigweed growth, even under the drier soil conditions. Weaver (1984) showed that the competitiveness of red root pigweed decreased at lower greenhouse temperatures of 22 °C / 14 °C (day / night) when compared to higher greenhouse temperatures of 28 °C / 22 °C, both temperatures in 16 hour photo-periods.

Although red root pigweed density did not have a significant effect on canola growth, there was a significant change in partitioning of biomass to leaves and stems of the canola plants the longer the red root pigweed competed with the canola (Figure 4.13). There was a significant decrease in leaf weight plant^{-1} when weeds were allowed to compete with the canola until the six leaf stage. Inter-specific competition between the red root pigweed and the canola, prior to canola bolting, may have caused canola to partition more of its biomass into the stems and not the leaves.

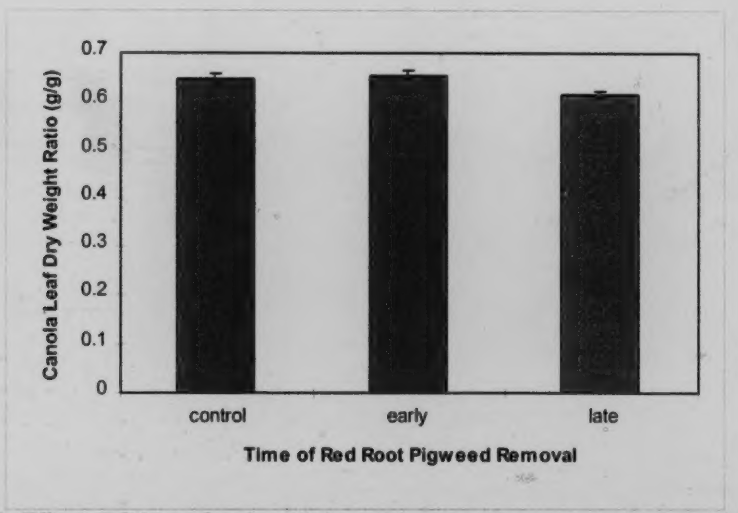

Figure 4.13 Effects of time of red root pigweed removal on canola leaf weight ratio (g/g). Red root pigweed was removed at 2 leaf stage (early), and 6 leaf stage (late) of canola. Data were averaged over two red root pigweed densities (high and low) and two moisture regimes (1/4 field capacity and field capacity). Standard error of the means was 0.008.

Limiting soil moisture had the most significant effect on canola dry matter production. In the experiment, all canola growth parameters measured, except leaf number, showed significant differences between 1/4 FC and FC moisture levels (Tables 4.3 and 7.4.5). The variables presented in Figure 4.14, except leaf weight ratio, showed significant increases moisture level increased. A similar response to moisture was also shown by Wiese and Vandiver (1970). The following plant species, corn (*Zea mays* L.), barnyardgrass (*Echinochloa crusgalli* L. Beauv.), cocklebur, large crabgrass (*Digitaria sanguinalis* L. Scop.), sorghum (*Sorghum vulgare* L. Var. RS 626), and Palmer amaranth (*Amaranthus palmeri* S. Wats.), increased plant weight in response to increased moisture.

Leaf weight ratio showed a significant decrease in partitioning biomass to the stem as water moisture increased (Figure 4.2). This result was different from that observed in the wild oat trial. The decrease in biomass partitioning to the stem was probably due to the higher canola leaf number in the red root pigweed trial than the wild oat trial at the time of harvest (Tables 4.1 and 7.4.3). In the wild oat trial, canola reached pre- bud at the 4 to 5.5 leaf stage, depending on wild oat density and moisture level. In the red root pigweed trial, canola reached the pre-bud stage at the 6 to 7 leaf stage of canola (Table 4.1). Canola, in the red root pigweed trial took 5 days longer to reach the 6 leaf stage (Table 4.1).

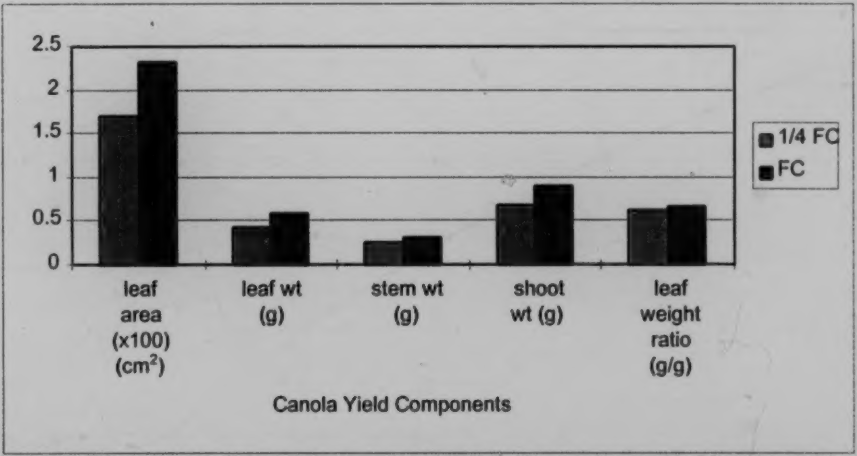

Figure 4.14 Effects of soil moisture on canola growth parameters. All data was expressed on a per plant basis. Moisture treatments were at 1/4 field capacity (1/4 FC) and field capacity (FC). Data were averaged over two red root pigweed densities (high and low) and two times of red root pigweed removal from the canola, the 3 leaf stage (early) and at 6 leaf stage (late). Standard errors of the means were presented in Appendix 7.4.5.

4.4 Conclusions

1. Increased time of wild oat competition and decreased moisture level, decreased canola growth parameters. The longer wild oat was allowed to remain in the crop the greater the effect on canola growth.

2. High wild oat density had less of an effect on canola leaf area and biomass production the earlier the wild oat was removed from the canola.
3. Low wild oat density at 1/4 FC had a similar effect as high wild oat density at FC on canola shoot weight. Increased moisture, decreased inter-specific competition between the canola and wild oat.
4. Red root pigweed was not competitive with the canola under the greenhouse conditions.

4. 5 References

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5

Chapter 5 The Effects of Single and Multiple Glyphosate Applications have on Glyphosate-Tolerant Canola

5.1 Introduction

Glyphosate is a widely used herbicide due to its ability to control many annual and perennial grass and broadleaf weeds and its environmental and safety characteristics (Conn and Deck, 1995; Darwent et al., 1994; Krausz et al., 1996; Lanie et al., 1994; Moseley and Hagood, 1991; Salisbury et al., 1991; Wilson and Worsham, 1988). Glyphosate is a foliar applied, non-selective herbicide that is translocated throughout the plant to actively growing tissues. Toxicity to mammals, birds and fish is low, and once applied, glyphosate persists in the soil for only a short period. It binds to the soil lattice and breaks down quickly, decreasing residual effects and possible leaching (Malik et al., 1989).

Glyphosate has been used as a pre-seeding application to control early emerging weeds, as a pre-harvest application to control perennial weeds, as a crop desiccant and as a post-harvest herbicide (Bruce and Kells, 1990; Kapusta and Krausz, 1993; Lick et al., 1997). Weed control with glyphosate varies depending on weed species, time of application, and rate of active ingredient. The application of glyphosate at low rates was most effective on young, annual weeds (Krausz et al., 1996). Glyphosate activity decreased as weeds matured, requiring higher rates of glyphosate to achieve tolerable levels of weed control (Krausz et al., 1996). Glyphosate at 1100 grams active ingredient ha^{-1} will control a broad spectrum of weeds in the mid-western United States (Krausz et al., 1996). The introduction of glyphosate tolerant crops has expanded the use of glyphosate as a post-emergent herbicide. The Round-up Ready Canola line GT-73, which contains the Round-up Ready™ genes is tolerant to glyphosate (Agriculture and Agri-Food Canada, 1995).

Glyphosate attacks the enzyme, 5-enolpyruvylshikimate-3-phosphate synthase (EPSPS) found in the shikimate pathway. This enzyme catalyzes the formation of the aromatic amino acids tryrosine, phenylalanine and tryptophan (Klee et al., 1987; Sherman et al., 1996). Glyphosate tolerant canola contains two bacterial derived genes (Agriculture and Agri-Food Canada, 1995). One gene reduces sensitivity to glyphosate at the active site, and the second gene produces an enzyme that degrades glyphosate. Thus, in the resistant plant, glyphosate is unable to inhibit the production of EPSPS.

There has been some research published on weed control using glyphosate as a post-emergent herbicide in glyphosate tolerant soybeans. There is little published information regarding the number of glyphosate applications and the optimal time that glyphosate can be applied with regards to possible negative effects on canola growth. Therefore, the objective of this experiment was to determine if multiple applications and timing of glyphosate application with regards to crop stage had a significant effect on growth of glyphosate-tolerant canola.

5.2 Method and Materials

5.2.1 Introduction

Greenhouse experiments were conducted at the University of Alberta in the Agricultural, Food and Nutritional Science greenhouses between September 3 and December 3, 1997. The purpose of the research was to investigate the effect that timing and number of applications of glyphosate had on the growth of glyphosate-tolerant canola.

5.2.2 Experimental Design

The experimental design was a randomized block with eight replications. The experiment was repeated. Glyphosate was applied at the 2, 4, 6, 2 & 4, 2 & 6, 4 & 6, 2, 4 & 6 leaf stages of canola. The experiment included an untreated control.

5.2.3 Greenhouse Climate

The greenhouse was set at 20 °C day and 18 °C night temperatures with a 16 hour photo-period supplemented with high intensity lighting from 400 watt, high pressure, sodium lamps. Light irradiance was 420 to 430 μE $m^{-2} s^{-1}$ at the soil surface, measured using a LI - COR (LI - 188) Integrating Quantum / Radiometer / Photometer.

5.2.4 Experiment Preparation and Glyphosate Application

The growth medium used was a mixture of peat, vermiculite and medium grade sand. The soil-less mixture included approximately 1:1:1/3 of peat:vermiculite:medium sand, by volume. To 36 liters (L) of the above mixture, the following nutrients were added: 270 g of dolomitic lime, 140 g of super phosphate (0-45-0), 240 g of 14 -14 -14, 2 g of iron chelate and 4 g of chelated trace elements (copper, zinc and iron) (Stringam, 1971). The peat and sand were autoclaved for 1 hour prior to soil mixing and use . Vermiculite was not autoclaved due to the possibility of toxicity problems. After autoclaving, the peat, sand, vermiculite, and nutrients were mixed together in a soil mixer and then transferred to 12.5 cm diameter pots. Pots were filled and canola seeded in the center of each pot. The canola cultivar was 'Quest'®. Once plants reached the first leaf stage, the canola was thinned to a single plant pot^{-1}. All pots were watered regularly.

The post-emergent herbicide used was liquid glyphosate [N-(phosphonomethyl)glycine] (356 grams $liter^{-1}$ ($g\ L^{-1}$) acid equivalent (a.e.)). Glyphosate was applied at 450 g a. e. $hectare^{-1}$ (ha^{-1}) using a spray chamber.

Water volume was 100 L ha^{-1}, at 275 kPa, 45 cm above the crop canopy with 8001 Teejet® nozzles.

5.2.5 Data Collection and Analysis

Canola plants were harvested ten days after the third glyphosate application. Leaves and stems were separated and the leaf area measured using a LI - COR (LI - 3100) area meter. Leaves and stems were then dried at 75 °C for 72 hours. Total shoot weight (above ground plant weight), specific leaf weight and leaf weight ratio [leaf dry weight / total shoot dry weight (g/g)] were calculated. Analysis of variance was performed on all parameters using SAS General Linear Model (GLM) procedure (SAS Institute Inc. 1996). Orthogonal contrasts were made between treatment means.

5.3 Results and Discussion

Analysis of variance on the combined data indicated significant treatment effects, depending on the canola growth parameter measured, between the glyphosate treatments and the untreated check (Table 5.1). Canola plants showed visual signs of injury after each application of glyphosate. Leaves that received glyphosate showed epidermal damage and plant tissues showed various levels of chlorosis. The amount of damage increased with the number of glyphosate applications made to the plant (Figures 5.1 and 5.2).

Table 5.1 Summary of analysis of variance for canola growth parameters after applications of glyphosate.

	Canola Growth Parameters (Pr > F)					
Source	**leaf area (cm^2)**	**leaf wt. (g)**	**stem wt. (g)**	**shoot wt. (g)**	**specific leaf wt. (g/cm^2)**	**leaf wt. ratio (g/g)**
Treatment	0.0001	0.0001	0.0001	0.0001	0.44	0.38
Trial * Treatment	0.44	0.82	0.18	0.39	0.61	0.62

Figure 5.1 Canola plants that received single and multiple applications of glyphosate. The smallest plant on the left received a triple application of glyphosate applied at the 2, 4, and 6 leaf stages of canola. The middle plant received a double application of glyphosate applied at the 4 and 6 leaf stages of canola and the plant on the right received a single application of glyphosate applied at the 2 leaf stage.

Figure 5.2 Leaf from a canola plant that received a triple application of glyphosate applied at the 2, 4, and 6 leaf stages of canola.

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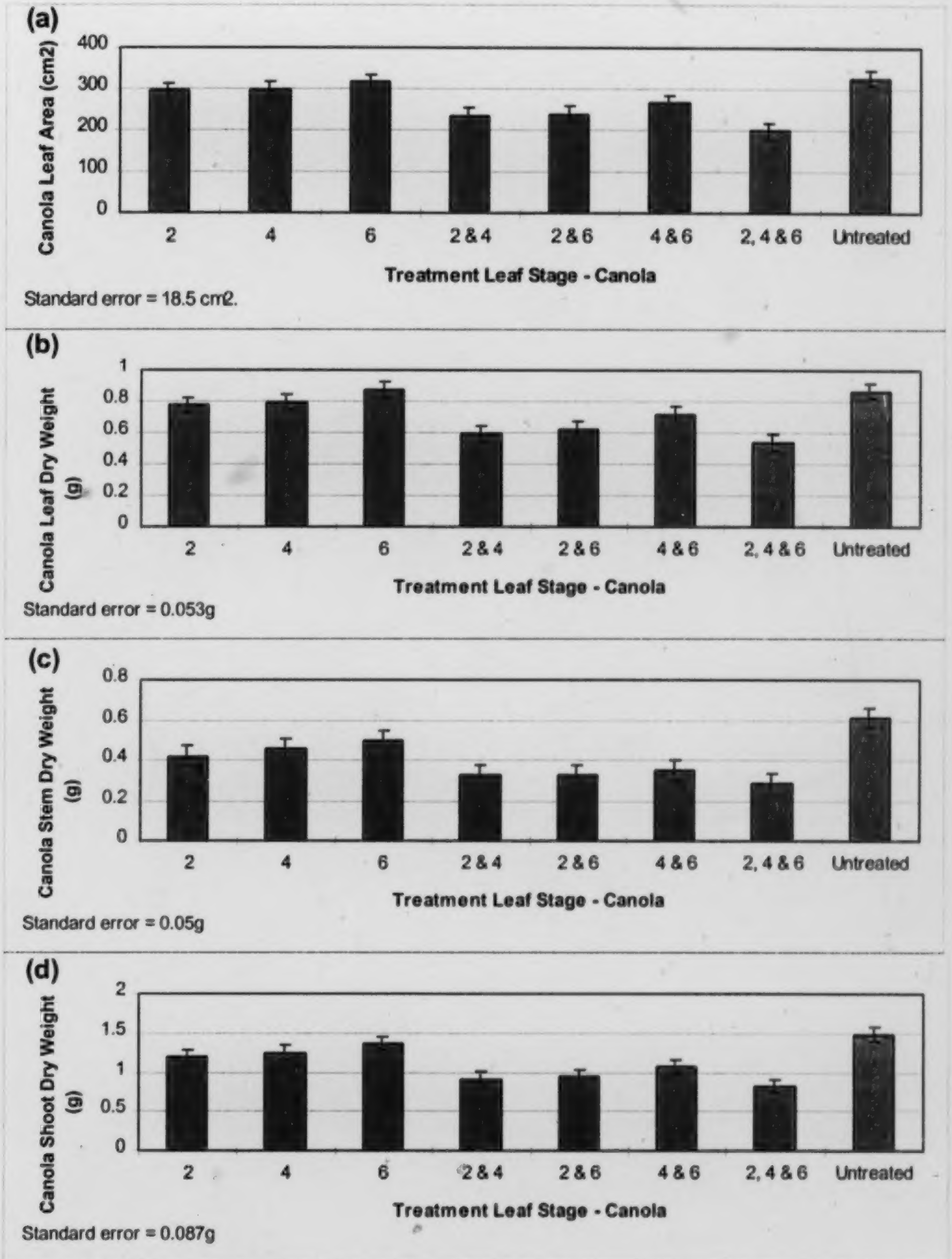
Canola leaf area and biomass differed depending on time of glyphosate application relative to canola growth stage, and the number of glyphosate applications (Figure 5.3). Multiple glyphosate applications decreased canola growth parameters more than single applications. Canola growth parameters were decreased further, the earlier glyphosate was applied. The highest leaf area and biomass was produced when no glyphosate was applied and the lowest leaf area and biomass was produced when three applications of glyphosate were made (Figure 5.1).



Standard error = 18.5 cm2.

Standard error = 0.053g

Standard error = 0.05g

Standard error = 0.087g

Figure 5.1 Treatment means for canola growth parameters: **a)** leaf area, **b)** leaf weight, **c)** stem weight and **d)** shoot weight.

Comparisons between the single glyphosate applications, (contrasts 1, 2, 3 vs 8), showed that canola stem weight and shoot weight were significantly higher in the untreated check than for single applications of glyphosate (Table 5.2). However, leaf area and leaf weight from the single glyphosate treatments were not significantly different from the untreated check. No significant differences occurred for leaf area and biomass production between the time of application of the three single glyphosate applications with regards to canola growth stage, even though earlier application of glyphosate resulted in lower canola leaf area and biomass. Comparisons of the double and triple glyphosate applications, (contrast 4, 5, 6 vs 8 and contrast 7 vs 8) showed that double and triple applications of glyphosate produced significantly lower canola growth parameters than the untreated check. Time of application for the double glyphosate treatment, did not significantly affect canola biomass.

Canola growth parameters were significantly higher when sprayed with a single application of glyphosate when compared to canola plants that had been sprayed with a double or triple application of glyphosate (Table 5.2). Comparisons between double glyphosate applications to triple glyphosate applications (contrast 4,5, 6 vs 7) were not as significant. A comparison between an early glyphosate application and an early / late glyphosate application (contrast 1 vs 5) showed that the canola leaf area, leaf weight and shoot weight were significantly higher for the early, single glyphosate application compared to the double glyphosate application. The yield loss recorded at Lacombe following an early / late application of glyphosate may have been caused by a slower crop growth following the double application. Stem weight was the only variable not significant at that level. This contrast (1 vs 5) showed all single glyphosate applications to be significantly higher for leaf area, leaf weight and shoot weight when compared to early / late (double) glyphosate applications (treatment 5) and early / mid glyphosate applications (treatment 4). Chapters 2 and 3 showed the importance of early glyphosate application in order to remove high weed pressures and prevent irreversible yield reductions. In the greenhouse experiment, late applications of glyphosate were less damaging to canola development. However, in the field, yield loss increased if the weeds were left to compete with the crop.

Glyphosate tends to be more effective on plants that are actively growing. Past research showed weed control with glyphosate decreased as % moisture and % relative humidity (%RH) decrease (McWhorter and Azlin, 1978). McWhorter and Azlin (1978) found glyphosate to be most effective on johnsongrass (*Sorghum halepense* L. Pers.) when RH was 100 % and soil moisture was 20 % (w/w) (approximately field capacity). Actively growing plants may translocate the herbicide more quickly to target sites. Resistant canola that is actively growing may not be able to break down glyphosate quickly enough when glyphosate is translocated to target sites rapidly.

Table 5.2 Orthogonal contrasts between single and multiple glyphosate applications for canola leaf area, leaf weight, stem weight and shoot weight.

	Measured Variable			
Treatment contrasts *	**Leaf area (cm^2)**	**Leaf wt. (g)**	**Stem wt. (g)**	**Shoot wt. (g)**
1,2,3 vs. 8	0.2	0.35	0.0077	0.04
4,5,6 vs. 8	0.0002	0.0003	0.0001	0.0001
1,2,3 vs. 7	0.0001	0.0001	0.005	0.0001
4,5,6 vs. 7	0.03	0.08	0.44	0.15
1,2,3 vs. 4,5,6	0.0003	0.0001	0.0034	0.0001
7 vs. 8	0.0001	0.0001	0.0001	0.0001
1 vs. 5	0.04	0.04	0.1816	0.05

*Canola growth stage regarding glyphosate application: treatment 1 = 2 leaf stage of canola, treatment 2 = 4 leaf stage of canola, treatment 3 = 6 leaf stage of canola, treatment 4 = treatments 1 and 2, treatment 5 = treatments 1 and 3, treatment 6 = treatments 2 and 3, treatment 7 = treatments 1, 2, and 3, and treatment 8 = no glyphosate (control).

5.4 Conclusions

1. Double and triple applications of glyphosate to glyphosate-tolerant canola cultivar 'Quest'$^{\circledR}$, not under moisture stress, significantly decreased canola leaf

area and biomass production when compared to single glyphosate applications and the untreated check.

2. Early glyphosate applications tended to decrease canola leaf area and biomass production more than late glyphosate applications.

3. Further research is required to test the canola growth response when treated with multiple applications of glyphosate when canola is under water stress. It will also be necessary to substantiate these results by testing under field conditions.

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Chapter 6 Synthesis

6.1 Summary of Results

The objectives of this thesis were to determine: 1) how time of weed removal with pre-plant incorporated (PPI) ethalfluralin and post-emergent glyphosate used alone and in sequence, affect canola yield; 2) the competitive effects of low and high wild oat and red root pigweed densities on glyphosate tolerant canola; 3) if one application of glyphosate is adequate or are two applications of glyphosate beneficial; and 4) the effects single and multiple glyphosate applications, applied at different stages of canola growth, have on biomass production of the glyphosate-tolerant canola cultivar, 'Quest'®. Research was conducted in the field for two field seasons and in the greenhouse. The effects of the treatments was investigated in the field under a wide range of soil and climatic conditions. The effects of the treatments on canola growth parameters were further investigated under controlled conditions.

Chapter 2 reported the effects wild oat densities and the time of wild oat removal had on canola yield. Wild oat competed strongly at both locations during both years. Combinations of PPI ethalfluralin and post-emergent glyphosate did not always result in a yield advantage compared to glyphosate alone. The double application of glyphosate, applied at an early and late stage of canola, did not necessarily increase yield compared to the early or late application of glyphosate, suggesting crop damage by the double application of glyphosate. At Lacombe, the double applications of glyphosate decreased canola yield compared to the single application of glyphosate.

Chapter 3 reported the effects red root pigweed densities and the time of red root pigweed removal on canola yield. Red root pigweed grew poorly compared to the canola; however, a number of broadleaf weeds emerged and competed with the canola. Early weed removal with PPI ethalfluralin did not significantly increase yield compared to glyphosate alone. Applications of post-emergent glyphosate to plots resulted in differences between harvested canola yield, depending on time of weed removal. Canola yield harvested from plots treated with an early application of glyphosate resulted in significantly higher canola yields when compared to canola yield harvested from plots treated with the double or the late application of glyphosate. Red root pigweed was not competitive with the canola under the prevailing growing conditions.

Chapter 4 reported on the competitive effects of both wild oat and red root pigweed on canola under greenhouse conditions. Each weed was seeded in separate experiments at high and low weed densities to study the competitive effects on canola growth parameters. Under the greenhouse conditions, wild oat competed strongly with the canola. Red root pigweed did not have a competitive effect on the canola. When canola was grown with wild oat at field capacity, extended weed competition had a greater effect on canola growth parameters than when weeds were removed early. Canola growth parameters decreased more rapidly, with later weed removal, at the high wild oat density than at the low wild oat density. At field capacity, there was a greater difference between high and low wild oat density than at 1/4 field capacity. Red root pigweed caused minimal affects on canola growth parameters.

Chapter 5 reported on the effects of single and multiple applications of glyphosate had on the canola growth parameters: leaf area, leaf weight, stem weight, and shoot weight. Canola plants were grown under greenhouse conditions with adequate moisture as single plants per pot. Single applications of glyphosate significantly decreased some canola growth parameters compared to the untreated check. As the number of glyphosate applications increased, there was a further decrease in canola growth parameters compared to the untreated check and single applications of glyphosate.

6.2 Agronomic Importance

At the locations that the field trials were conducted, wild oat was more competitive with canola than red root pigweed. In the canola - red root pigweed competition trial, canola grew quickly and was able to close its leaf canopy early in the growing season. Wild oat was able to grow with the canola and elongate above the canola canopy. It appeared that wild oat was more competitive with canola than red root pigweed with canola. This may be because wild oat and red root pigweed have similar life cycles. Red root pigweed is more of a problem in crops grown in drier areas, and with row crops that have a higher heat unit requirement than canola.

In the greenhouse experiment when wild oat was allowed to compete with the canola, particularly if moisture was limited, canola growth parameters were significantly reduced. Canola growth parameters decreased more rapidly with later weed removal at the high wild oat density than at the low wild oat density. Moisture had the greatest effect on canola growth parameters when canola competed with the low wild oat density compared to the high wild oat density. Pigweed had minimal affect on canola growth parameters when grown in competition experiments in the greenhouse. Under the greenhouse conditions, red root pigweed, a C-4 species, was not competitive against canola, and may not significantly affect canola yield in the field under similar growing conditions.

An early application of glyphosate caused increased yield compared to a late application of glyphosate, even though weeds were allowed to compete with the crop for an extended period of time (up to the 2 to 3 leaf stage of canola). The use of PPI ethalfluralin did not always increase canola yield. At Lacombe in 1997, the application of ethalfluralin prior to glyphosate increased yield compared to applications of glyphosate alone. Crop injury was observed when double applications of glyphosate were applied at an early and late stage of canola growth. The response of canola to double applications of glyphosate varied with geographic location. The plants may be more susceptible when growing vigorously under optimum growing conditions. Where crops are subjected to several flushes of weed germination during the growing season, a PPI herbicide followed by a single application of glyphosate may be more beneficial than several sequential glyphosate applications.

In the greenhouse when glyphosate was applied as single and multiple applications to the canola at various stages of growth, canola growth parameters decreased with increased glyphosate application. The double and triple applications of glyphosate resulted in significant decreases in canola biomass when compared to either the single or untreated applications of glyphosate. Damage from glyphosate applications declined as the age of the plants at application increased.

6.3 General Conclusions

1. At Lacombe, the double application of glyphosate, applied at early and late growth stages of canola, generally caused a decrease of canola yield compared to the early application of glyphosate. The double application of glyphosate suggests crop damage; producers may not always receive an advantage by controlling a second flush of weeds with a second application of glyphosate.
2. At Vegreville, the differences in canola yield between the early and the double application of glyphosate were not significant. The longer the weeds compete with the crop, the greater the yield loss. Early weed removal significantly increased canola yield.
3. If no herbicide was applied, high wild oat densities decreased canola yield more than low wild oat densities.
4. Under controlled growing conditions, multiple applications of glyphosate slowed the growth rate of 'Quest' canola and there was evidence of epidermal

damage to the leaves. Very young canola seedlings, 2 to 3 leaf stage, were more sensitive to glyphosate application than older 6 leaf stage plants.

5. An application of ethalfluralin prior to glyphosate did not always increase canola yield.

7.0 APPENDICES

7.1 Appendices for Wild Oat Field Trial

Table 7.1.1 Analysis of variance for canola yield from wild oat trial. Trial (T) included locations and year, Lacombe 1996 and 1997 and Vegreville 1996 and 1997. Pre-plant incorporated (PPI) herbicide (H) was the main plot and included treatments of ethalfluralin and no ethalfluralin. Density (D) was sub plot and included high and low wild oat densities. Treatment (Tr) was the sub-sub plot and included hand-weeded check and post-emergent herbicide applications (POST) no glyphosate, early application of glyphosate, early and late applications of glyphosate and late application of glyphosate.

Source	DF	F-value	Prob.
Trial (T)	3	57.65	0.0001
Rep (Trial)	20	--	--
PPI Herbicide (H)	1	100.53	0.0001
H x T	3	7.57	0.0001
Error 1	20	--	--
Density (D)	1	19.51	0.0001
D x T	3	0.55	0.6487
D x H	1	13.64	0.0003
D x H x T	3	0.23	0.8783
Error 2	40	--	--
Treatment (Tr)	4	49.63	0.0001
Tr x T	12	4.37	0.0001
Tr x H	4	34.62	0.0001
Tr x H x T	12	2.11	0.0163
Tr x D	4	3.64	0.0064
Tr x D x T	12	0.95	0.4944
Tr x D x H	4	4.62	0.0012
Tr x D x H x T	12	1.33	0.2002
Error 3	320	--	--

Table 7.1.2 Canola yield (kg ha^{-1}) for trials (location and year) Lacombe, 1996, Lacombe, 1997, Vegreville, 1996, and Vegreville, 1997. Yields from the four trials included means averaged over two ethalfluralin treatments, two wild oat density treatments and one hand-weeded check and four glyphosate treatments.

Trial	Yield (kg ha^{-1})
Lacombe 1996	4412
Lacombe 1997	4009
Vegreville 1996	4336
Vegreville 1997	3751

Standard Error for means was 106 kg ha^{-1}.

Table 7.1.3 Canola yield (kg ha^{-1}) from pre-plant incorporated (PPI) herbicide treatments. Yields from both herbicide treatments included means averaged over four trials (location and year), two wild oat density treatments, and hand-weeded check and four glyphosate treatments.

PPI Herbicide	**Yield (kg ha^{-1})**
Ethalfluralin	4329
No Ethalfluralin	3925

Standard Error for means was 32 kg ha^{-1}.

Table 7.1.4 Canola yield (kg ha^{-1}) for trial by pre-plant incorporated (PPI) herbicide interaction. Trials (location and year) included Lacombe, 1996, Lacombe, 1997, Vegreville, 1996, and Vegreville, 1997. PPI herbicide treatments included ethalfluralin and no ethalfluralin. The means were averaged over two wild oat density treatments, and one hand-weeded check and four glyphosate treatments.

Trial	**PPI Herbicide**	**Yield (kg ha^{-1})**
Lacombe 1996 [1]	Ethalfluralin	4487
	No Ethalfluralin	4338
Lacombe 1997 [2]	Ethalfluralin	4257
	No Ethalfluralin	3761
Vegreville 1996 [3]	Ethalfluralin	4665
	No Ethalfluralin	4009
Vegreville 1997 [4]	Ethalfluralin	3907
	No Ethalfluralin	3596

[1] Standard Error for Lacombe 1996 means was 80 kg ha^{-1}.
[2] Standard Error for Lacombe 1997 means was 50 kg ha^{-1}.
[3] Standard Error for Vegreville 1996 means was 58 kg ha^{-1}.
[4] Standard Error for Vegreville 1997 means was 67 kg ha^{-1}.
Standard Error for all four trial means was 65 kg ha^{-1}.

Table 7.1.5 Canola yield (kg ha^{-1}) for high and low wild oat density treatments. Wild oat density treatment means were averaged over four trials, two ethalfluralin treatments, and hand-weeded check and four glyphosate treatments.

Weed Density	**Yield (kg ha^{-1})**
High	4038
Low	4217

Standard Error for means was 34 kg ha^{-1}.

Table 7.1.6 Canola yield (kg ha^{-1}) for trial by wild oat density interaction. Trials (location and year) included Lacombe, 1996, Lacombe, 1997, Vegreville, 1996 and Vegreville, 1997. Wild oat density treatments included high and low wild oat densities. The means were averaged over two ethalfluralin treatments, and one hand-weeded check and four glyphosate treatments.

Trial	Weed Density	Yield (kg ha^{-1})
Lacombe 1996 [1]	High	4329
	Low	4496
Lacombe 1997 [2]	High	3882
	Low	4135
Vegreville 1996 [3]	High	4284
	Low	4390
Vegreville 1997 [4]	High	3658
	Low	3844

[1] Standard Error for Lacombe 1996 means was 70 kg ha^{-1}.
[2] Standard Error for Lacombe 1997 means was 46 kg ha^{-1}.
[3] Standard Error for Vegreville 1996 means was 60 kg ha^{-1}.
[4] Standard Error for Vegreville 1997 means was 84 kg ha^{-1}.
Standard Error for all four trial means was 67 kg ha^{-1}.

Table 7.1.7 Canola yield (kg ha^{-1}) for herbicide by wild oat density interaction. Pre plant incorporated (PPI) herbicide treatments included ethalfluralin and no ethalfluralin. Wild oat density treatments included high and low weed densities. The means were averaged over four trials, and one hand-weeded check and four glyphosate treatments.

PPI Herbicide	Weed Density	Yield (kg ha^{-1})
Ethalfluralin	High	4314
	Low	4344
No Ethalfluralin	High	3763
	Low	4089

Standard Error for means was 47 kg ha^{-1}.

Table 7.1.8 Canola yield (kg ha^{-1}) for trial by herbicide by wild oat density interaction. Trials (location and year) included Lacombe, 1996, Lacombe, 1997, Vegreville, 1996, and Vegreville, 1997. Pre plant incorporated (PPI) herbicide treatments included ethalfluralin and no ethalfluralin. Wild oat density treatments included high and low weed densities. The means were averaged over four trials, and one hand-weeded check and four glyphosate treatments.

Trial	PPI Herbicide	Weed Density	Yield (kg ha^{-1})
Lacombe 1996 [1]	**Ethalfluralin**	High	4471
		Low	4502
	No Ethalfluralin	High	4186
		Low	4489
Lacombe 1997 [2]	**Ethalfluralin**	High	4230
		Low	4284
	No Ethalfluralin	High	3535
		Low	3986
Vegreville 1996 [3]	**Ethalfluralin**	High	4665
		Low	4664
	No Ethalfluralin	High	3902
		Low	4115
Vegreville 1997 [4]	**Ethalfluralin**	High	3889
		Low	3924
	No Ethalfluralin	High	3426
		Low	3764

[1] Standard Error for Lacombe 1996 means was 99 kg ha^{-1}.
[2] Standard Error for Lacombe 1997 means was 67 kg ha^{-1}.
[3] Standard Error for Vegreville 1996 means was 85 kg ha^{-1}.
[4] Standard Error for Vegreville 1997 means was 120 kg ha^{-1}.
Standard Error for all four trial means was 94 kg ha^{-1}.

Table 7.1.9 Canola yield (kg ha^{-1}) for glyphosate and hand-weeded treatments. Treatments included hand-weeded check, no glyphosate, early application of glyphosate, early and late application of glyphosate, and late application of glyphosate. The means were averaged over four trials, two ethalfluralin treatments and two wild oat density treatments.

Treatment	Yield (kg ha^{-1})
Hand-Weeded	4264
No glyphosate	3570
Early glyphosate	4365
Early / Late glyphosate	4229
Late glyphosate	4208

Standard Error for means was 45 kg ha^{-1}.

Table 7.1.10 Canola yield (kg ha^{-1}) for trial by treatment interaction. Trials (location and year) included Lacombe, 1996, Lacombe, 1997, Vegreville, 1996, and Vegreville, 1997. Treatments included hand-weeded check, no glyphosate, early application of glyphosate, early and late application of glyphosate, and late application of glyphosate. The means were averaged over two ethalfluralin treatments and two wild oat density treatments.

Trial	Treatment	Yield (kg ha^{-1})
Lacombe 1996 [1]	**Hand-weeded**	4692
	No glyphosate	4042
	Early glyphosate	4554
	Early / Late glyphosate	4255
	Late glyphosate	4517
Lacombe 1997 [2]	**Hand-weeded**	4221
	No glyphosate	3602
	Early glyphosate	4165
	Early / Late glyphosate	3959
	Late glyphosate	4098
Vegreville 1996 [3]	**Hand-weeded**	4473
	No glyphosate	3525
	Early glyphosate	4648
	Early / Late glyphosate	4585
	Late glyphosate	4453
Vegreville 1997 [4]	**Hand-weeded**	3669
	No glyphosate	3112
	Early glyphosate	4091
	Early / Late glyphosate	4119
	Late glyphosate	3764

[1] Standard Error for Lacombe 1996 means was 91 kg ha^{-1}.
[2] Standard Error for Lacombe 1997 means was 94 kg ha^{-1}.
[3] Standard Error for Vegreville 1996 means was 59 kg ha^{-1}.
[4] Standard Error for Vegreville 1997 means was 106 kg ha^{-1}.
Standard Error for all four trial means was 89 kg ha^{-1}.

Table 7.1.11 Canola yield (kg ha^{-1}) for herbicide by treatment interaction. Pre plant incorporated (PPI) herbicide included ethalfluralin and no ethalfluralin. Treatments included hand-weeded check, no glyphosate, early application of glyphosate, early and late application of glyphosate, and late application of glyphosate. The means were averaged over four trials and two wild oat density treatments.

PPI Herbicide	Treatment	Yield (kg ha^{-1})
Ethalfluralin	**Hand-weeded**	4456
	No glyphosate	4228
	Early glyphosate	4438
	Early / Late glyphosate	4223
	Late glyphosate	4298
No Ethalfluralin	**Hand-weeded**	4071
	No glyphosate	2912
	Early glyphosate	4291
	Early / Late glyphosate	4235
	Late glyphosate	4118

Standard Error for means was 63 kg ha^{-1}.

Table 7.1.12 Canola yield for three way interaction, trial by pre-plant incorporated (PPI) herbicide by treatment. Trials (location and year) included Lacombe, 1996, Lacombe, 1997, Vegreville, 1996, and Vegreville, 1997. PPI herbicide included ethalfluralin and no ethalfluralin. Treatments included hand-weeded check, no glyphosate, early application of glyphosate, early and late application of glyphosate, and late application of glyphosate. The means were averaged over two wild oat density treatments.

Trial	PPI Herbicide	Treatment	Yield (kg ha^{-1})
Lacombe 1996 [1]	**Ethalfluralin**	**Hand-weeded**	4710
		No glyphosate	4457
		Early glyphosate	4635
		Early / Late glyphosate	4228
		Late glyphosate	4403
	No Ethalfluralin	**Hand-weeded**	4674
		No glyphosate	3627
		Early glyphosate	4474
		Early / Late glyphosate	4282
		Late glyphosate	4632
Lacombe 1997 [2]	**Ethalfluralin**	**Hand-weeded**	4493
		No glyphosate	4342
		Early glyphosate	4225
		Early / Late glyphosate	3888
		Late glyphosate	4339
	No Ethalfluralin	**Hand-weeded**	3949
		No glyphosate	2863
		Early glyphosate	4105
		Early / Late glyphosate	4029
		Late glyphosate	3857
Vegreville 1996 [3]	**Ethalfluralin**	**Hand-weeded**	4834
		No glyphosate	4525
		Early glyphosate	4822
		Early / Late glyphosate	4619
		Late glyphosate	4522
	No Ethalfluralin	**Hand-weeded**	4112
		No glyphosate	2523
		Early glyphosate	4474
		Early / Late glyphosate	4550
		Late glyphosate	4383
Vegreville 1997 [4]	**Ethalfluralin**	**Hand-weeded**	3790
		No glyphosate	3588
		Early glyphosate	4071
		Early / Late glyphosate	4156
		Late glyphosate	3927
	No Ethalfluralin	**Hand-weeded**	3548
		No glyphosate	2637
		Early glyphosate	4111
		Early / Late glyphosate	4081
		Late glyphosate	3600

[1] Standard Error for Lacombe 1996 means was 128 kg ha^{-1}.
[2] Standard Error for Lacombe 1997 means was 134 kg ha^{-1}.
[3] Standard Error for Vegreville 1996 means was 83 kg ha^{-1}.
[4] Standard Error for Vegreville 1997 means was 150 kg ha^{-1}.
Standard Error for all four trial means was 126 kg ha^{-1}.

Table 7.1.13 Canola yield for three way interaction, trial by weed density by treatment. Trials (location and year) included Lacombe, 1996, Lacombe, 1997, Vegreville, 1996, and Vegreville, 1997. Weed density included high and low wild oat densities. Treatments included hand-weeded check, no glyphosate, early application of glyphosate, early and late application of glyphosate, and late application of glyphosate. The means were averaged over two pre-plant incorporated treatments.

Trial	Weed Density	Treatment	Yield (kg ha^{-1})
Lacombe 1996 [1]	**High**	**Hand-weeded**	4682
		No glyphosate	3758
		Early glyphosate	4481
		Early / Late glyphosate	4251
		Late glyphosate	4469
	Low	**Hand-weeded**	4702
		No glyphosate	4325
		Early glyphosate	4627
		Early / Late glyphosate	4259
		Late glyphosate	4565
Lacombe 1997 [2]	**High**	**Hand-weeded**	4131
		No glyphosate	3221
		Early glyphosate	4216
		Early / Late glyphosate	3860
		Late glyphosate	3984
	Low	**Hand-weeded**	4310
		No glyphosate	3983
		Early glyphosate	4113
		Early / Late glyphosate	4057
		Late glyphosate	4212
Vegreville 1996 [3]	**High**	**Hand-weeded**	4440
		No glyphosate	3315
		Early glyphosate	4603
		Early / Late glyphosate	4595
		Late glyphosate	4466
	Low	**Hand-weeded**	4506
		No glyphosate	3733
		Early glyphosate	4693
		Early / Late glyphosate	4574
		Late glyphosate	4440
Vegreville 1997 [4]	**High**	**Hand-weeded**	3677
		No glyphosate	3024
		Early glyphosate	3961
		Early / Late glyphosate	3914
		Late glyphosate	3712
	Low	**Hand-weeded**	3661
		No glyphosate	3201
		Early glyphosate	4221
		Early / Late glyphosate	4323
		Late glyphosate	3816

[1] Standard Error for Lacombe 1996 means was 128 kg ha^{-1}.
[2] Standard Error for Lacombe 1997 means was 134 kg ha^{-1}.
[3] Standard Error for Vegreville 1996 means was 83 kg ha^{-1}.
[4] Standard Error for Vegreville 1997 means was 150 kg ha^{-1}.
Standard Error for all four trial means was 126 kg ha^{-1}.

Table 7.1.14 Canola yield for wild oat densities by hand weeded and glyphosate treatment interaction. Wild oat densities included high and low weed density pressures. Treatments included hand-weeded check, no glyphosate, early application of glyphosate, early and late application of glyphosate, and late application of glyphosate. The means were averaged over four trials and two pre-plant incorporated treatments.

Weed Density	Treatment	Yield (kg ha^{-1})
High	**Hand-weeded**	4232
	No glyphosate	3329
	Early glyphosate	4315
	Early / Late glyphosate	4155
	Late glyphosate	4158
Low	**Hand-weeded**	4295
	No glyphosate	3810
	Early glyphosate	4414
	Early / Late glyphosate	4303
	Late glyphosate	4258

Standard Error for means was 63 kg ha^{-1}.

Table 7.1.15 Canola yield (kg ha^{-1}) for three way interaction, pre-plant incorporated (PPI) herbicide by wild oat density by hand-weeded and glyphosate treatments. PPI herbicide included ethalfluralin and no ethalfluralin. Wild oat density treatments included high and low weed densities. Treatments included hand-weeded check, no glyphosate, early application of glyphosate, early and late application of glyphosate, and late application of glyphosate. The means were averaged over four locations.

PPI Herbicide	Weed Density	Treatment	Yield (kg ha^{-1})
Ethalfluralin	**High**	**Hand-weeded**	4541
		No glyphosate	4207
		Early glyphosate	4357
		Early / Late glyphosate	4178
		Late glyphosate	4285
	Low	**Hand-weeded**	4372
		No glyphosate	4249
		Early glyphosate	4519
		Early / Late glyphosate	4267
		Late glyphosate	4311
No Ethalfluralin	**High**	**Hand-weeded**	3924
		No glyphosate	2452
		Early glyphosate	4273
		Early / Late glyphosate	4132
		Late glyphosate	4030
	Low	**Hand-weeded**	4218
		No glyphosate	3372
		Early glyphosate	4309
		Early / Late glyphosate	4339
		Late glyphosate	4206

Standard Error for means was 89 kg ha^{-1}.

Table 7.1.16 Lacombe 1996, canola yield (kg ha^{-1}) for three way interaction, pre-plant incorporated (PPI) herbicide by wild oat density by hand-weeded and glyphosate treatments. PPI herbicide included ethalfluralin and no ethalfluralin. Wild oat density treatments included high and low weed densities. Treatments included hand-weeded check, no glyphosate, early application of glyphosate, early and late application of glyphosate, and late application of glyphosate.

PPI Herbicide	Weed Density	Treatment	Yield (kg ha^{-1})
Ethalfluralin	**High**	**Hand-weeded**	4830
		No glyphosate	4459
		Early glyphosate	4413
		Early / Late glyphosate	4318
		Late glyphosate	4335
	Low	**Hand-weeded**	4590
		No glyphosate	4454
		Early glyphosate	4856
		Early / Late glyphosate	4139
		Late glyphosate	4471
No Ethalfluralin	**High**	**Hand-weeded**	4535
		No glyphosate	3057
		Early glyphosate	4549
		Early / Late glyphosate	4184
		Late glyphosate	4604
	Low	**Hand-weeded**	4814
		No glyphosate	4195
		Early glyphosate	4399
		Early / Late glyphosate	4380
		Late glyphosate	4656

Standard Error for Lacombe 1996 means was 182 kg ha^{-1}.

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Table 7.1.17 Lacombe 1997, canola yield (kg ha^{-1}) for three way interaction, pre-plant incorporated (PPI) herbicide by wild oat density by hand-weeded and glyphosate treatments. PPI herbicide included ethalfluralin and no ethalfluralin. Wild oat density treatments included high and low weed densities. Treatments included hand-weeded check, no glyphosate, early application of glyphosate, early and late application of glyphosate, and late application of glyphosate.

PPI Herbicide	**Weed Density**	**Treatment**	**Yield (kg ha^{-1})**
Ethalfluralin	**High**	**Hand-weeded**	4472
		No glyphosate	4235
		Early glyphosate	4169
		Early / Late glyphosate	3899
		Late glyphosate	4374
	Low	**Hand-weeded**	4512
		No glyphosate	4448
		Early glyphosate	4279
		Early / Late glyphosate	3877
		Late glyphosate	4304
No Ethalfluralin	**High**	**Hand-weeded**	3790
		No glyphosate	2207
		Early glyphosate	4264
		Early / Late glyphosate	3821
		Late glyphosate	3594
	Low	**Hand-weeded**	4108
		No glyphosate	3518
		Early glyphosate	3947
		Early / Late glyphosate	4237
		Late glyphosate	4119

Standard Error for Lacombe 1996 means was 189 kg ha^{-1}.

Table 7.1.18 Vegreville 1996, canola yield (kg ha^{-1}) for three way interaction, pre-plant incorporated (PPI) herbicide by wild oat density by hand-weeded and glyphosate treatments. PPI herbicide included ethalfluralin and no ethalfluralin. Wild oat density treatments included high and low weed densities. Treatments included hand-weeded check, no glyphosate, early application of glyphosate, early and late application of glyphosate, and late application of glyphosate.

PPI Herbicide	Weed Density	Treatment	Yield (kg ha^{-1})
Ethalfluralin	**High**	**Hand-weeded**	4834
		No glyphosate	4490
		Early glyphosate	4828
		Early / Late glyphosate	4675
		Late glyphosate	4499
	Low	**Hand-weeded**	4836
		No glyphosate	4560
		Early glyphosate	4816
		Early / Late glyphosate	4563
		Late glyphosate	4545
No Ethalfluralin	**High**	**Hand-weeded**	4047
		No glyphosate	2140
		Early glyphosate	4377
		Early / Late glyphosate	4515
		Late glyphosate	4432
	Low	**Hand-weeded**	4177
		No glyphosate	2906
		Early glyphosate	4570
		Early / Late glyphosate	4586
		Late glyphosate	4335

Standard Error for Vegreville 1996 means was 118 kg ha^{-1}.

Table 7.1.19 Vegreville 1997, canola yield (kg ha^{-1}) for three way interaction, pre plant incorporated (PPI) herbicide by wild oat density by hand-weeded and glyphosate treatments. PPI herbicide included ethalfluralin and no ethalfluralin. Wild oat density treatments included high and low weed densities. Treatments included hand-weeded check, no glyphosate, early application of glyphosate, early and late application of glyphosate, and late application of glyphosate.

PPI Herbicide	Weed Density	Treatment	Yield (kg ha^{-1})
Ethalfluralin	**High**	**Hand-weeded**	4029
		No glyphosate	3643
		Early glyphosate	4019
		Early / Late glyphosate	3822
		Late glyphosate	3933
	Low	**Hand-weeded**	3551
		No glyphosate	3533
		Early glyphosate	4124
		Early / Late glyphosate	4491
		Late glyphosate	3921
No Ethalfluralin	**High**	**Hand-weeded**	3325
		No glyphosate	2406
		Early glyphosate	3903
		Early / Late glyphosate	4007
		Late glyphosate	3491
	Low	**Hand-weeded**	3771
		No glyphosate	2868
		Early glyphosate	4319
		Early / Late glyphosate	4154
		Late glyphosate	3710

Standard Error for Vegreville 1997 means was 212 kg ha^{-1}.

Table 7.1.20 Lacombe 1996 weed pressure for wild oat trial at time of second application of glyphosate.

	Weed Species and Weed Pressure (plants m^{-2})		
Ethalfluralin x wild oat density	**Wild Oat**	**Lamb's Quarter**	**Stink Weed**
Ethalfluralin-low	2 - 4	0 - 2	0 - 20
Ethalfluralin-high	5 - 10	0 - 2	0 - 20
No Ethalfluralin-low	40 - 45	10 - 20	0 - 20
No Ethalfluralin-high	150 - 170	10	0 - 5

Table 7.1.21 Lacombe 1997 weed pressure for wild oat trial at time of second application of glyphosate.

	Weed Species and Weed Pressure (plants m^{-2})	
Ethalfluralin x wild oat density	**Wild Oat**	**Lamb's Quarter**
Ethalfluralin-low	2	0
Ethalfluralin-high	4 - 5	0
No Ethalfluralin-low	40 - 50	15 - 25
No Ethalfluralin-high	150 - 180	10 - 20

Table 7.1.22 Vegreville 1996 weed pressure for wild oat trial at time of second application of glyphosate.

	Weed Species and Weed Pressure (plants m^{-2})			
Ethalfluralin x wild oat density	**Wild Oat**	**Lamb's Quarter**	**Smart Weed**	**Wild Buckwheat**
Ethalfluralin-low	2-5	1	5 - 10	0 - 1
Ethalfluralin-high	10 - 15	1	5 - 10	0 - 1
No Ethalfluralin-low	50	5-15	5-10	5
No Ethalfluralin-high	200	5-15	5	1 - 5

Table 7.1.23 Vegreville 1997 weed pressure for wild oat trial at time of second application of glyphosate.

	Weed Species and Weed Pressure (plants m^{-2})		
Ethalfluralin x wild oat density	**Wild Oat**	**Lamb's Quarter**	**Stink Weed**
Ethalfluralin-low	0 - 1	1 - 2	10 - 30
Ethalfluralin-high	0 - 5	1 - 2	10 - 30
No Ethalfluralin-low	40 - 50	20	10 - 30
No Ethalfluralin-high	200	5 - 10	5 - 20

Table 7.1.24 Lacombe 1996 and 1997 average % weed control from weed control ratings taken three weeks after the late application of glyphosate.

		Weed Species and % Weed Control		
Herbicide		**Wild Oat**	**Lambs quarters**	**Stink Weed**
Ethalfluralin	early glyphosate	100	100	100
	late glyphosate	100	100	95
	e / l glyphosate	100	100	100
	no glyphosate	95	95	0
No Ethalfluralin	early glyphosate	99	97	100
	late glyphosate	99	94	95
	e / l glyphosate	100	100	100
	no glyphosate	0	0	0

Table 7.1.25 Vegreville 1996 and 1997 average % weed control from weed control ratings taken three weeks after the late application of glyphosate.

		Weed Species and % Weed Control				
Herbicide		**Wild Oat**	**Lambs quarters**	**Stink Weed**	**Wild Buckwheat**	**Smart Weed**
Ethalfluralin	early glyphosate	100	100	99	98	98
	late glyphosate	100	100	98	98	98
	e / l glyphosate	100	100	100	100	100
	no glyphosate	95	95	0	90	80
No Ethalfluralin	early glyphosate	100	95	99	90	96
	late glyphosate	95	90	98	80	90
	e / l glyphosate	100	100	100	100	100
	no glyphosate	0	0	0	0	0

7.2 Appendices for Red Root Pigweed Field Trial

Table 7.2.1 Analysis of variance for canola yield from red root pigweed trial. Trial (T) included locations and year, Lacombe 1996 and 1997 and Vegreville 1996 and 1997. Pre-plant incorporated (PPI) herbicide (H) was the main plot and included PPI herbicide treatments of ethalfluralin and no ethalfluralin. Density (D) was sub plot and included high and low red root pigweed densities. Treatment (Tr) was the sub-sub plot and included hand-weeded check and post emergent herbicide applications (POST) no glyphosate, early application of glyphosate, early and late applications of glyphosate and late application of glyphosate.

Source	DF	F-value	Prob.
Trial (T)	3	174	0.0001
Rep (Trial)	20	--	--
PPI Herbicide (H)	1	0.14	0.7087
H x T	3	6.23	0.0004
Error 1	20	--	--
Density (D)	1	11.9	0.0006
D x T	3	4.09	0.0072
D x H	1	0.03	0.8562
D x H x T	3	0.10	0.9591
Error 2	40	--	--
Treatment (Tr)	4	8.42	0.0001
Tr x T	12	4.33	0.0001
Tr x H	4	3.80	0.0049
Tr x H x T	12	1.50	0.1235
Tr x D	4	1.77	0.1348
Tr x D x T	12	0.31	0.9875
Tr x D x H	4	0.79	0.5343
Tr x D x H x T	12	0.42	0.9555
Error 3	320	--	--

Table 7.2.2 Canola yield (kg ha^{-1}) for trial (location and year). Trials included Lacombe, 1996, Lacombe, 1997, Vegreville, 1996, and Vegreville, 1997. The means were averaged over two ethalfluralin treatments, two red root pigweed density treatments, and hand-weeded check and four glyphosate treatments.

Trial	Yield (kg ha^{-1})
Lacombe 1996	4073
Lacombe 1997	3651
Vegreville 1996	4902
Vegreville 1997	4412

Standard Error for means was 154 kg ha^{-1}.

Table 7.2.3 Canola yield (kg ha^{-1}) from pre-plant incorporated (PPI) herbicide treatments. Yields from both herbicide treatments included means averaged over four trials (location and year), two red root pigweed density treatments, and hand-weeded check and four glyphosate treatments.

PPI Herbicide	**Yield (kg ha^{-1})**
Ethalfluralin	4268
No Ethalfluralin	4254

Standard Error for means was 92 kg ha^{-1}.

Table 7.2.4 Canola yield (kg ha^{-1}) for trial by herbicide interaction. Trials (location and year) included Lacombe, 1996, Lacombe, 1997, Vegreville, 1996, and Vegreville, 1997. Pre-plant incorporated (PPI) herbicide treatments included ethalfluralin and no ethalfluralin. The means were averaged over two red root pigweed density treatments, and one hand-weeded check and four glyphosate treatments.

Trial	**PPI Herbicide**	**Yield (kg ha^{-1})**
Lacombe 1996 [1]	Ethalfluralin	4108
	No Ethalfluralin	4038
Lacombe 1997 [2]	Ethalfluralin	3742
	No Ethalfluralin	3561
Vegreville 1996 [3]	Ethalfluralin	4765
	No Ethalfluralin	5040
Vegreville 1997 [4]	Ethalfluralin	4454
	No Ethalfluralin	4370

[1] Standard Error for Lacombe 1996 means was 80 kg ha^{-1}.
[2] Standard Error for Lacombe 1997 means was 57 kg ha^{-1}.
[3] Standard Error for Vegreville 1996 means was 50 kg ha^{-1}.
[4] Standard Error for Vegreville 1997 means was 67 kg ha^{-1}.
Standard Error for all four trial means was 65 kg ha^{-1}.

Table 7.2.5 Canola yield (kg ha^{-1}) for high and low red root pigweed densities. Red root pigweed treatment means were averaged over four trials, two ethalfluralin treatments, and hand-weeded check and four glyphosate treatments.

Weed Density	**Yield (kg ha^{-1})**
High	4190
Low	4329

Standard Error for means was 48 kg ha^{-1}.

Table 7.2.6 Canola yield (kg ha^{-1}) for trial by red root pigweed density interaction. Trials (location and year) included Lacombe, 1996, Lacombe, 1997, Vegreville, 1996, and Vegreville, 1997. Red root pigweed density treatments included high and low red root pigweed densities. The means were averaged over two ethalfluralin treatments, and one hand-weeded check and four glyphosate treatments.

Trial	**Weed Density**	**Yield (kg ha^{-1})**
Lacombe 1996 [1]	High	3967
	Low	4179
Lacombe 1997 [2]	High	3501
	Low	3812
Vegreville 1996 [3]	High	4854
	Low	4951
Vegreville 1997 [4]	High	4445
	Low	4379

[1] Standard Error for Lacombe 1996 means was 91 kg ha^{-1}.
[2] Standard Error for Lacombe 1997 means was 101 kg ha^{-1}.
[3] Standard Error for Vegreville 1996 means was 100 kg ha^{-1}.
[4] Standard Error for Vegreville 1997 means was 87 kg ha^{-1}.
Standard Error for all four trial means was 95 kg ha^{-1}.

Table 7.2.7 Canola yield (kg ha^{-1}) for herbicide by red root pigweed density interaction. Pre plant incorporated (PPI) herbicide treatments included ethalfluralin and no ethalfluralin. Red root pigweed density treatments included high and low weed densities. The means were averaged over four trials, and one hand-weeded check and four glyphosate treatments.

PPI Herbicide	**Weed Density**	**Yield (kg ha^{-1})**
Ethalfluralin	High	4195
	Low	4340
No Ethalfluralin	High	4187
	Low	4318

Standard Error for means was 95 kg ha^{-1}.

Table 7.2.8 Canola yield (kg ha^{-1}) for trial by herbicide by red root pigweed density interaction. Trials (location and year) included Lacombe, 1996, Lacombe, 1997, Vegreville, 1996, and Vegreville, 1997. Pre-plant incorporated (PPI) herbicide treatments included ethalfluralin and no ethalfluralin. Red root pigweed density treatments included high and low weed densities. The means were averaged over four trials, and one hand-weeded check and four glyphosate treatments.

Trial	**PPI Herbicide**	**Weed Density**	**Yield (kg ha^{-1})**
Lacombe 1996 [1]	**Ethalfluralin**	High	4017
		Low	4199
	No Ethalfluralin	High	3917
		Low	4158
Lacombe 1997 [2]	**Ethalfluralin**	High	3575
		Low	3909
	No Ethalfluralin	High	3417
		Low	3704
Vegreville 1996 [3]	**Ethalfluralin**	High	4712
		Low	4817
	No Ethalfluralin	High	4995
		Low	5084
Vegreville 1997 [4]	**Ethalfluralin**	High	4474
		Low	4434
	No Ethalfluralin	High	4416
		Low	4323

[1] Standard Error for Lacombe 1996 means was kg ha^{-1}.

[2] Standard Error for Lacombe 1997 means was kg ha^{-1}.

[3] Standard Error for Vegreville 1996 means was kg ha^{-1}.

[4] Standard Error for Vegreville 1997 means was kg ha^{-1}.

Standard Error for all four trial means was 135 kg ha^{-1}.

Table 7.2.9 Canola yield (kg ha^{-1}) for glyphosate and hand-weeded treatments. Treatments included hand-weeded check, no glyphosate, early application of glyphosate, early and late application of glyphosate and late application of glyphosate. The means were averaged over four trials, two ethalfluralin treatments, two red root pigweed density treatments, and hand-weeded check and four glyphosate treatments.

Treatment	**Yield (kg ha^{-1})**
Hand-Weeded	4298
No glyphosate	4051
Early glyphosate	4408
Early / Late glyphosate	4257
Late glyphosate	4283

Standard Error for means was 45 kg ha^{-1}.

Table 7.2.10 Canola yield (kg ha^{-1}) for trial by treatment interaction. Trials (location and year) included Lacombe, 1996, Lacombe, 1997, Vegreville, 1996, and Vegreville, 1997. Treatments included hand-weeded check, no glyphosate, early application of glyphosate, early and late application of glyphosate, and late application of glyphosate. The means were averaged over two pre-plant incorporated treatments, and two red root pigweed density treatments.

Trial	Treatment	Yield (kg ha^{-1})
Lacombe 1996 [1]	**Hand-weeded**	4208
	No glyphosate	3997
	Early glyphosate	4147
	Early / Late glyphosate	3897
	Late glyphosate	4116
Lacombe 1997 [2]	**Hand-weeded**	3764
	No glyphosate	3541
	Early glyphosate	3820
	Early / Late glyphosate	3526
	Late glyphosate	3607
Vegreville 1996 [3]	**Hand-weeded**	4992
	No glyphosate	4799
	Early glyphosate	5014
	Early / Late glyphosate	4924
	Late glyphosate	4781
Vegreville 1997 [4]	**Hand-weeded**	4229
	No glyphosate	3868
	Early glyphosate	4652
	Early / Late glyphosate	4683
	Late glyphosate	4629

[1] Standard Error for Lacombe 1996 means was 80 kg ha^{-1}.
[2] Standard Error for Lacombe 1997 means was 57 kg ha^{-1}.
[3] Standard Error for Vegreville 1996 means was 50 kg ha^{-1}.
[4] Standard Error for Vegreville 1997 means was 67 kg ha^{-1}.
Standard Error for all four trial means was 65 kg ha^{-1}.

Table 7.2.11 Canola yield (kg ha^{-1}) for pre-plant incorporated (PPI) herbicide by treatment interaction. PPI herbicide included ethalfluralin and no ethalfluralin. Treatments included hand-weeded check, no glyphosate, early application of glyphosate, early and late application of glyphosate, and late application of glyphosate. The means were averaged over four trials, and two red root pigweed density treatments.

PPI Herbicide	Treatment	Yield (kg ha^{-1})
Ethalfluralin	**Hand-weeded**	4331
	No glyphosate	4191
	Early glyphosate	4333
	Early / Late glyphosate	4191
	Late glyphosate	4289
No Ethalfluralin	**Hand-weeded**	4266
	No glyphosate	3911
	Early glyphosate	4483
	Early / Late glyphosate	4324
	Late glyphosate	4278

Standard Error for means was 63 kg ha^{-1}.

Table 7.2.12 Canola yield for three way interaction, trial by pre-plant incorporated herbicide by treatment. Trials (location and year) included Lacombe, 1996, Lacombe, 1997, Vegreville, 1996, and Vegreville, 1997. PPI herbicide included ethalfluralin and no ethalfluralin. Treatments included hand-weeded check, no glyphosate, early application of glyphosate, early and late application of glyphosate, and late application of glyphosate. The means were averaged over two wild oat density treatments.

Trial	PPI Herbicide	Treatment	Yield (kg ha^{-1})
Lacombe 1996 [1]	**Ethalfluralin**	**Hand-weeded**	4242
		No glyphosate	4047
		Early glyphosate	4134
		Early / Late glyphosate	3973
		Late glyphosate	4144
	No Ethalfluralin	**Hand-weeded**	4175
		No glyphosate	3946
		Early glyphosate	4159
		Early / Late glyphosate	3821
		Late glyphosate	4088
Lacombe 1997 [2]	**Ethalfluralin**	**Hand-weeded**	3799
		No glyphosate	3806
		Early glyphosate	3846
		Early / Late glyphosate	3527
		Late glyphosate	3733
	No Ethalfluralin	**Hand-weeded**	3728
		No glyphosate	3276
		Early glyphosate	3795
		Early / Late glyphosate	3524
		Late glyphosate	3482
Vegreville 1996 [3]	**Ethalfluralin**	**Hand-weeded**	3852
		No glyphosate	4705
		Early glyphosate	4870
		Early / Late glyphosate	4772
		Late glyphosate	4621
	No Ethalfluralin	**Hand-weeded**	5132
		No glyphosate	4893
		Early glyphosate	5157
		Early / Late glyphosate	5077
		Late glyphosate	4941
Vegreville 1997 [4]	**Ethalfluralin**	**Hand-weeded**	4431
		No glyphosate	4207
		Early glyphosate	4483
		Early / Late glyphosate	4493
		Late glyphosate	4657
	No Ethalfluralin	**Hand-weeded**	4028
		No glyphosate	3528
		Early glyphosate	4820
		Early / Late glyphosate	4872
		Late glyphosate	4601

[1] Standard Error for Lacombe 1996 means was 138 kg ha^{-1}.
[2] Standard Error for Lacombe 1997 means was 153 kg ha^{-1}.
[3] Standard Error for Vegreville 1996 means was 79 kg ha^{-1}.
[4] Standard Error for Vegreville 1997 means was 123 kg ha^{-1}.
Standard Error for all four trial means was 126 kg ha^{-1}.

Table 7.1.13 Canola yield for three way interaction, trial by weed density by treatment. Trials (location and year) included Lacombe, 1996, Lacombe, 1997, Vegreville, 1996, and Vegreville, 1997. Weed density included high and low red root pigweed densities. Treatments included hand-weeded check, no glyphosate, early application of glyphosate, early and late application of glyphosate, and late application of glyphosate. The means were averaged over two pre-plant incorporated treatments.

Trial	Weed Density	Treatment	Yield (kg ha^{-1})
Lacombe 1996 [1]	**High**	**Hand-weeded**	4071
		No glyphosate	3794
		Early glyphosate	4048
		Early / Late glyphosate	3766
		Late glyphosate	4156
	Low	**Hand-weeded**	4345
		No glyphosate	4199
		Early glyphosate	4244
		Early / Late glyphosate	4028
		Late glyphosate	4077
Lacombe 1997 [2]	**High**	**Hand-weeded**	3557
		No glyphosate	3309
		Early glyphosate	3760
		Early / Late glyphosate	3316
		Late glyphosate	3564
	Low	**Hand-weeded**	3970
		No glyphosate	3823
		Early glyphosate	3881
		Early / Late glyphosate	3735
		Late glyphosate	3650
Vegreville 1996 [3]	**High**	**Hand-weeded**	4960
		No glyphosate	4725
		Early glyphosate	5007
		Early / Late glyphosate	4826
		Late glyphosate	4749
	Low	**Hand-weeded**	5024
		No glyphosate	4874
		Early glyphosate	5020
		Early / Late glyphosate	5023
		Late glyphosate	4813
Vegreville 1997 [4]	**High**	**Hand-weeded**	4296
		No glyphosate	3899
		Early glyphosate	4699
		Early / Late glyphosate	4626
		Late glyphosate	4706
	Low	**Hand-weeded**	4162
		No glyphosate	3836
		Early glyphosate	4604
		Early / Late glyphosate	4740
		Late glyphosate	4551

[1] Standard Error for Lacombe 1996 means was 138 kg ha^{-1}.
[2] Standard Error for Lacombe 1997 means was 153 kg ha^{-1}.
[3] Standard Error for Vegreville 1996 means was 79 kg ha^{-1}.
[4] Standard Error for Vegreville 1997 means was 123 kg ha^{-1}.
Standard Error for all four trial means was 126 kg ha^{-1}.

Table 7.2.14 Canola yield for red root pigweed densities by hand weeded and glyphosate treatment interaction. Red root pigweed densities included high and low weed density pressures. Treatments included hand-weeded check, no glyphosate, early application of glyphosate, early and late application of glyphosate, and late application of glyphosate. The means were averaged over four trials and two ethalfluralin treatments.

Weed Density	Treatment	Yield (kg ha^{-1})
High	**Hand-weeded**	4221
	No glyphosate	3926
	Early glyphosate	4378
	Early / Late glyphosate	4133
	Late glyphosate	4295
Low	**Hand-weeded**	4375
	No glyphosate	4177
	Early glyphosate	4437
	Early / Late glyphosate	4381
	Late glyphosate	4273

Standard Error for means was 63 kg ha^{-1}.

Table 7.2.15 Canola yield (kg ha^{-1}) for three way interaction, pre-plant incorporated (PPI) herbicide by red root pigweed density by hand-weeded and glyphosate treatments. PPI herbicide included ethalfluralin and no ethalfluralin. Red root pigweed density treatments included high and low weed densities. Treatments included hand-weeded check, no glyphosate, early application of glyphosate, early and late application of glyphosate, and late application of glyphosate. The means were averaged over four locations.

PPI Herbicide	Weed Density	Treatment	Yield (kg ha^{-1})
Ethalfluralin	**High**	**Hand-weeded**	4266
		No glyphosate	4086
		Early glyphosate	4341
		Early / Late glyphosate	4041
		Late glyphosate	4238
	Low	**Hand-weeded**	4396
		No glyphosate	4297
		Early glyphosate	4325
		Early / Late glyphosate	4341
		Late glyphosate	4340
No Ethalfluralin	**High**	**Hand-weeded**	4176
		No glyphosate	3765
		Early glyphosate	4416
		Early / Late glyphosate	4225
		Late glyphosate	4350
	Low	**Hand-weeded**	4355
		No glyphosate	4056
		Early glyphosate	4549
		Early / Late glyphosate	4422
		Late glyphosate	4206

Standard Error for means was 89 kg ha^{-1}.

Table 7.2.16 Lacombe 1996, canola yield (kg ha^{-1}) for three way interaction, pre-plant incorporated (PPI) herbicide by red root pigweed density by hand-weeded and glyphosate treatments. PPI herbicide included ethalfluralin and no ethalfluralin. Red root pigweed density treatments included high and low weed densities. Treatments included hand-weeded check, no glyphosate, early application of glyphosate, early and late application of glyphosate, and late application of glyphosate.

PPI Herbicide	Weed Density	Treatment	Yield (kg ha^{-1})
Ethalfluralin	**High**	**Hand-weeded**	4048
		No glyphosate	3814
		Early glyphosate	4167
		Early / Late glyphosate	3857
		Late glyphosate	4197
	Low	**Hand-weeded**	4435
		No glyphosate	4280
		Early glyphosate	4101
		Early / Late glyphosate	4089
		Late glyphosate	4091
No Ethalfluralin	**High**	**Hand-weeded**	4094
		No glyphosate	3774
		Early glyphosate	3930
		Early / Late glyphosate	3675
		Late glyphosate	4114
	Low	**Hand-weeded**	4256
		No glyphosate	4118
		Early glyphosate	4388
		Early / Late glyphosate	3967
		Late glyphosate	4062

Standard Error for Lacombe 1996 means was 195 kg ha^{-1}.

Table 7.2.17 Lacombe 1997, canola yield (kg ha^{-1}) for three way interaction, pre-plant incorporated (PPI) herbicide by red root pigweed density by hand-weeded and glyphosate treatments. PPI herbicide included ethalfluralin and no ethalfluralin. Red root pigweed density treatments included high and low weed densities. Treatments included hand-weeded check, no glyphosate, early application of glyphosate, early and late application of glyphosate, and late application of glyphosate.

PPI Herbicide	Weed Density	Treatment	Yield (kg ha^{-1})
Ethalfluralin	**High**	**Hand-weeded**	3606
		No glyphosate	3554
		Early glyphosate	3809
		Early / Late glyphosate	3262
		Late glyphosate	3656
	Low	**Hand-weeded**	3992
		No glyphosate	4079
		Early glyphosate	3882
		Early / Late glyphosate	3791
		Late glyphosate	3810
No Ethalfluralin	**High**	**Hand-weeded**	3508
		No glyphosate	3063
		Early glyphosate	3711
		Early / Late glyphosate	3370
		Late glyphosate	3472
	Low	**Hand-weeded**	3949
		No glyphosate	3567
		Early glyphosate	3879
		Early / Late glyphosate	3679
		Late glyphosate	3491

Standard Error for Lacombe 1996 means was 217 kg ha^{-1}.

Table 7.2.18 Vegreville 1996, canola yield (kg ha^{-1}) for three way interaction, pre-plant incorporated (PPI) herbicide by red root pigweed density by hand-weeded and glyphosate treatments. PPI herbicide treatment included ethalfluralin and no ethalfluralin. Red root pigweed density treatments included high and low weed densities. Treatments included hand-weeded check, no glyphosate, early application of glyphosate, early and late application of glyphosate, and late application of glyphosate.

PPI Herbicide	Weed Density	Treatment	Yield (kg ha^{-1})
Ethalfluralin	**High**	**Hand-weeded**	4873
		No glyphosate	4676
		Early glyphosate	4865
		Early / Late glyphosate	4632
		Late glyphosate	4512
	Low	**Hand-weeded**	4831
		No glyphosate	4734
		Early glyphosate	4875
		Early / Late glyphosate	4913
		Late glyphosate	4731
No Ethalfluralin	**High**	**Hand-weeded**	5048
		No glyphosate	4774
		Early glyphosate	5149
		Early / Late glyphosate	5020
		Late glyphosate	4987
	Low	**Hand-weeded**	5216
		No glyphosate	5013
		Early glyphosate	5165
		Early / Late glyphosate	5133
		Late glyphosate	4895

Standard Error for Vegreville 1996 means was 111 kg ha^{-1}.

Table 7.2.19 Vegreville 1997, canola yield (kg ha^{-1}) for three way interaction, pre-plant incorporated (PPI) herbicide by red root pigweed density by hand-weeded and glyphosate treatments. PPI herbicide treatments included ethalfluralin and no ethalfluralin. Red root pigweed density treatments included high and low weed densities. Treatments included hand-weeded check, no glyphosate, early application of glyphosate, early and late application of glyphosate, and late application of glyphosate.

PPI Herbicide	Weed Density	Treatment	Yield (kg ha^{-1})
Ethalfluralin	**High**	**Hand-weeded**	4536
		No glyphosate	4311
		Early glyphosate	4524
		Early / Late glyphosate	4415
		Late glyphosate	4586
	Low	**Hand-weeded**	4325
		No glyphosate	4104
		Early glyphosate	4443
		Early / Late glyphosate	4572
		Late glyphosate	4727
No Ethalfluralin	**High**	**Hand-weeded**	4056
		No glyphosate	3487
		Early glyphosate	4875
		Early / Late glyphosate	4836
		Late glyphosate	4827
	Low	**Hand-weeded**	3999
		No glyphosate	3569
		Early glyphosate	4766
		Early / Late glyphosate	4909
		Late glyphosate	4375

Standard Error for Vegreville 1997 means was 174 kg ha^{-1}.

Table 7.2.20 Lacombe 1996 weed pressure for red root pigweed trial at time of second application of glyphosate.

	Weed Species and Weed Pressure (plants m^{-2})		
Ethalfluralin x red root pigweed density	**Red Root Pigweed**	**Lamb's Quarter**	**Stink Weed**
Ethalfluralin-low	0	0 - 2	0 - 20
Ethalfluralin-high	2 - 3	0 - 2	0 - 20
No Ethalfluralin-low	2 - 30	10 - 20	0 - 20
No Ethalfluralin-high	10 - 30	5 - 10	0 - 10

Table 7.2.21 Lacombe 1997 weed pressure for red root pigweed trial at time of second application of glyphosate.

	Weed Species and Weed Pressure (plants m^{-2})		
Ethalfluralin x red root pigweed density	**Red Root Pigweed**	**Lamb's Quarter**	**Stink Weed**
Ethalfluralin-low	0	0	2
Ethalfluralin-high	0	0	2
No Ethalfluralin-low	0 - 10	5 - 15	2
No Ethalfluralin-high	5 - 20	5 - 10	2

Table 7.2.22 Vegreville 1996 weed pressure for red root pigweed trial at time of second application of glyphosate.

	Weed Species and Weed Pressure (plants m^{-2})			
Ethalfluralin x red root pigweed density	**Red Root Pigweed**	**Lamb's Quarter**	**Stink Weed**	**Smart Weed**
Ethalfluralin-low	0	0 - 2	5 - 10	5
Ethalfluralin-high	2	0 - 2	5 - 10	5
No Ethalfluralin-low	10	10 - 20	5 - 10	5 - 10
No Ethalfluralin-high	25 - 30	10 - 20	5 - 10	5 - 10

Table 7.2.23 Vegreville 1997 weed pressure for red root pigweed trial at time of second application of glyphosate.

	Weed Species and Weed Pressure (plants m^{-2})			
Ethalfluralin x red root pigweed density	**Red Root Pigweed**	**Lamb's Quarter**	**Stink Weed**	**Common Groundsel**
Ethalfluralin-low	0 - 1	0 - 2	5 - 10	5 - 10
Ethalfluralin-high	0 - 2	0 - 2	5 - 10	5 - 10
No Ethalfluralin-low	5 - 30	5 - 15	5 - 10	5 - 10
No Ethalfluralin-high	5 - 40	5	5 - 15	2 - 10

Table 7.2.24 Lacombe 1996 and 1997 average % weed control from weed control ratings three weeks after late application of glyphosate.

		Weed Species and % Weed Control		
Herbicide		**Red Root Pigweed**	**Lambs quarters**	**Stink Weed**
Ethalfluralin	early glyphosate	100	100	100
	late glyphosate	100	100	100
	e / l glyphosate	100	100	100
	no glyphosate	95	95	0
No Ethalfluralin	early glyphosate	100	100	100
	late glyphosate	97	95	100
	e / l glyphosate	100	100	100
	no glyphosate	0	0	0

Table 7.2.25 Vegreville 96 and 97 average % weed control from weed control ratings three weeks after late application of glyphosate.

		Weed Species and % Weed Control				
Herbicide		**Red Root Pigweed**	**Lambs quarters**	**Stink Weed**	**Smart Weed**	**Common Groundsel**
Ethalfluralin	early glyphosate	100	100	100	100	99
	late glyphosate	100	100	99	97	98
	e / l glyphosate	100	100	100	100	100
	no glyphosate	97	95	0	75	0
No Ethalfluralin	early glyphosate	98	98	100	98	98
	late glyphosate	95	90	94	93	98
	e / l glyphosate	100	100	100	100	100
	no glyphosate	0	0	0	0	0

7.3 Appendices for 1996 and 1997 Weather data for Lacombe and Vegreville

Table 7.3.1 Weather Data for Lacombe from 1907 to 1990

	Precipitation	Temperature (°C)		
Time Period	**Total**	**Max**	**Min**	**Mean**
April	20.3	10.2	-2.7	3.8
May	49.8	17.1	3.0	10.1
June	74.9	10.7	7.3	14.0
July	86.0	22.6	9.1	15.8
August	65.2	22.0	8.0	15.0
September	47.4	16.8	3.1	10.0
October	16.7	11.8	-2.2	4.8

Table 7.3.2 Weather Data for Vegreville from 1956 to 1990

	Precipitation	Temperature (°C)		
Time Period	**Total**	**Max**	**Min**	**Mean**
April	16.0	9.6	-2.9	3.4
May	38.3	17.6	3.1	10.4
June	73.0	21.4	7.4	14.4
July	83.2	22.9	9.5	16.2
August	61.3	22.3	8.1	15.2
September	41.1	16.4	3.1	9.8
October	14.8	10.7	-2.4	4.2

Table 7.3.3 Weekly weather data for Lacombe 1996.

	Precipitation (mm)				Temperature (Degrees Celsius)			
	Weekly Period		Since April 1st					
Time Period	Total	Normal	Total	% Normal	Max	Min	Mean	From Normal
01-Apr to 07-Apr	8.9	4.0	8.9	223.0	15.8	-15.8	-1.5	-2.3
08-Apr to 14-Apr	5.0	4.7	13.9	160.0	18.5	-1.6	4.3	1.5
15-Apr to 21-Apr	19.3	5.9	33.2	228.0	19.5	-2.4	6.3	2.0
22-Apr to 28-Apr	2.2	4.9	35.4	182.0	16.7	-3.6	6.7	0.6
29-Apr to 05-May	37.8	9.8	73.2	251.0	13.3	-1.8	5.2	-2.4
06-May to 12-May	21.5	8.9	94.7	249.0	14.7	-7.3	0.2	-8.5
13-May to 19-May	28.6	10.3	123.3	255.0	17.9	1.1	9.9	0.1
20-May to 26-May	2.0	13.2	125.3	204.0	22.7	0.3	9.8	-2.1
27-May to 02-Jun	23.4	11.8	148.0	203.0	22.8	2.8	11.4	-1.0
03-Jun to 09-Jun	9.6	16.7	158.3	176.0	30.0	3.6	15.2	1.8
10-Jun to 16-Jun	2.8	19.6	161.1	147.0	26.3	1.5	14.6	0.8
17-Jun to 23-Jun	58.6	15.2	219.7	176.0	18.1	2.4	9.0	-5.5
24-Jun to 30-Jun	9.6	21.3	229.3	157.0	22.1	4.0	12.2	-2.4
01-Jul to 07-Jul	20.4	27.1	249.7	144.0	24.9	6.3	15.5	0.4
08-Jul to 14-Jul	70.0	16.4	319.7	169.0	25.5	4.6	15.8	-0.2
15-Jul to 21-Jul	7.0	18.3	326.7	157.0	25.7	3.4	14.8	-0.9
22-Jul to 28-Jul	11.6	19.6	338.6	149.0	25.1	6.7	15.7	-0.5
29-Jul to 04-Aug	41.8	15.6	380.1	157.0	27.1	7.8	16.7	0.1
05-Aug to 11-Aug	4.6	12.6	384.7	151.0	29.0	4.5	15.6	-0.6
12-Aug to 18-Aug	4.0	17.2	388.7	143.0	28.3	1.4	14.8	-0.2
19-Aug to 25-Aug	0.2	10.6	388.9	137.0	29.1	1.6	14.3	0.1
26-Aug to 01-Sep	2.0	13.8	390.9	132.0	32.5	6.8	18.8	5.5
02-Sep to 08-Sep	7.0	14.3	397.9	128.0	18.7	-1.2	8.5	-3.2
09-Sep to 15-Sep	10.6	12.5	408.5	126.0	27.0	1.9	13.6	3.5
16-Sep to 22-Sep	41.6	10.5	450.1	135.0	13.7	-3.2	7.1	-2.1
23-Sep to 29-Sep	11.5	7.2	461.6	135.0	16.5	-3.7	4.7	-3.8
30-Sep to 06-Oct	19.6	7.3	481.2	138.0	21.1	-1.7	5.4	-2.2
07-Oct to 13-Oct	6.1	3.1	487.3	138.0	21.8	-1.9	8.4	1.9
14-Oct to 20-Oct	1.5	1.9	488.8	138.0	14.1	-7.4	2.0	-2.9
21-Oct to 27-Oct	2.3	3.9	491.1	137.0	11.7	-8.1	1.9	-0.9
28-Oct to 31-Oct	7.8	0.9	498.9	139.0	7.1	-15.3	-4.7	-6.2

Table 7.3.4 Weekly weather data for Vegreville 1996.

	Precipitation (mm)				**Temperature (Degrees Celsius)**			
	Weekly Period		**Since April 1st**					
Time Period	**Total**	**Normal**	**Total**	**% Normal**	**Max**	**Min**	**Mean**	**From Normal**
01-Apr to 07-Apr	0.6	3.0	0.6	20.0	15.6	-18.5	-2.5	-2.2
08-Apr to 14-Apr	3.6	4.8	4.2	54.0	16.9	-2.6	4.3	2.2
15-Apr to 21-Apr	7.4	3.0	11.6	107.0	19.3	-3.0	5.5	1.3
22-Apr to 28-Apr	12.9	4.0	24.5	166.0	14.7	-4.4	4.8	-1.6
29-Apr to 05-May	3.2	7.0	27.7	127.0	13.8	-1.3	6.1	-1.5
06-May to 12-May	2.8	5.4	30.5	112.0	14.5	-5.8	1.3	-7.7
13-May to 19-May	17.3	11.6	47.8	123.0	17.1	0.1	8.5	-1.5
20-May to 26-May	5.2	10.0	53.0	109.0	20.2	1.4	8.7	-3.5
27-May to 02-Jun	9.2	7.1	62.2	111.0	21.8	3.7	11.3	-1.6
03-Jun to 09-Jun	29.2	17.1	91.4	125.0	26.6	6.5	15.4	1.5
10-Jun to 16-Jun	3.8	14.4	95.2	109.0	24.1	5.3	14.2	0.2
17-Jun to 23-Jun	17.8	18.4	113.0	107.0	22.1	3.9	9.7	-5.2
24-Jun to 30-Jun	6.4	23.7	119.4	92.0	22.4	1.7	11.7	-3.5
01-Jul to 07-Jul	5.8	19.6	125.2	84.0	26.0	6.9	15.8	0.0
08-Jul to 14-Jul	25.8	22.7	151.0	88.0	27.5	7.3	15.7	-0.7
15-Jul to 21-Jul	9.0	19.7	160.0	83.0	24.4	4.1	14.6	-1.5
22-Jul to 28-Jul	16.4	16.4	176.4	85.0	23.9	6.9	15.6	-0.7
29-Jul to 04-Aug	47.8	16.8	224.2	100.0	26.5	5.9	16.0	-0.9
05-Aug to 11-Aug	9.2	12.8	233.4	98.0	26.0	6.1	15.0	-1.4
12-Aug to 18-Aug	5.2	12.5	238.6	95.0	27.3	3.2	14.7	-0.5
19-Aug to 25-Aug	0.0	10.5	238.6	92.0	27.5	4.3	14.4	0.0
26-Aug to 01-Sep	0.0	17.2	238.6	86.0	31.4	6.9	17.7	4.4
02-Sep to 08-Sep	16.4	12.8	255.0	88.0	15.6	-0.8	8.4	-3.3
09-Sep to 15-Sep	0.0	8.2	255.0	85.0	24.9	-0.9	13.3	3.2
16-Sep to 22-Sep	46.2	8.4	301.2	98.0	14.3	-1.7	8.1	-0.9
23-Sep to 29-Sep	15.4	5.2	316.6	101.0	12.5	-4.6	4.3	-3.8
30-Sep to 06-Oct	0.2	4.4	316.8	100.0	20.5	-5.7	3.5	-3.5
07-Oct to 13-Oct	0.6	2.8	317.4	99.0	19.8	-1.3	8.6	2.6
14-Oct to 20-Oct	0.2	3.0	317.6	98.0	13.7	-10.5	0.9	-3.3
21-Oct to 27-Oct	5.5	3.6	323.1	99.0	9.0	-7.1	0.8	-1.2
28-Oct to 31-Oct	0.8	1.1	323.9	99.0	2.2	-15.2	-8.0	8.3

Table 7.3.5 Weekly weather data for Lacombe 1997.

	Precipitation (mm)				Temperature (Degrees Celsius)			
	Weekly Period		Since April 1st					
Time Period	Total	Normal	Total	% Normal	Max	Min	Mean	From Normal
31-Mar to 06-Apr	4	4.2	190.1*	233*	9.7	-17.1	-3.5	-3.9
07-Apr to 13-Apr	1.3	4.4	4.6	57	12.8	-15.0	-4.6	-7.0
14-Apr to 20-Apr	10.8	5.7	15.4	112	21.1	-3.8	6.3	2.2
21-Apr to 27-Apr	1.5	5.2	16.9	89	17.7	-3.0	6.2	0.3
28-Apr to 04-May	0.2	9.0	17.1	61	16.7	-4.7	6.1	-1.3
05-May to 11-May	1.1	8.3	18.2	50	20.6	-2.7	9.0	0.5
12-May to 18-May	4.0	11.1	22.2	47	26.0	0.6	11.8	2.2
19-May to 25-May	49.0	12.4	71.2	119	12.2	-3.6	5.3	-6.2
26-May to 01-Jun	7.2	11.7	78.4	110	25.4	3.9	13.7	1.5
02-Jun to 08-Jun	23.2	15.7	101.6	117	22.5	4.1	14.3	0.9
09-Jun to 15-Jun	10.0	20.0	111.6	104	24.7	5.4	16.4	2.9
16-Jun to 22-Jun	67.0	14.7	178.6	147	25.4	4.7	13.7	-0.8
23-Jun to 29-Jun	5.2	21.4	183.8	128	24.3	3.5	12.7	-1.9
30-Jun to 06-Jul	0.2	28.6	184.0	107	24.8	5.1	13.8	-1.2
07-Jul to 13-Jul	9.8	15	193.8	104	23.7	5.2	14.6	-1.3
14-Jul to 20-Jul	33.8	19.1	227.6	111	27.4	6.5	16.7	1.1
21-Jul to 27-Jul	6.2	16.6	233.8	105	27.9	3.4	14.8	-1.4
28-Jul to 03-Aug	34.0	18.1	267.8	111	29.7	5.6	17.9	1.4
04-Aug to 10-Aug	8.6	14.5	276.4	108	32.6	2.3	16.8	0.4
11-Aug to 17-Aug	24.6	15.9	301.0	111	23.8	6.3	113.6	-1.5
18-Aug to 24-Aug	1.8	11.4	302.8	107	29.0	4.0	15.9	1.5
25-Aug to 31-Aug	2.6	13.5	305.4	103	27.5	2.2	13.5	0.2
01-Sep to 07-Sep	17.0	13.6	322.4	104	28.8	1.7	13.7	1.6
08-Sep to 14-Sep	10.0	13.5	332.4	103	25.9	1.1	10.9	0.7
15-Sep to 21-Sep	34.9	10.2	367.3	110	23.2	-3.2	7.7	-1.6
22-Sep to 28-Sep	0.2	8.3	367.5	108	28.1	0.3	13.2	4.6
29-Sep to 05-Oct	0.4	6.5	367.9	106	25.7	-4.0	8.0	0.1
06-Oct to 12-Oct	4.7	4.0	372.6	106	13.5	-6.3	0.0	-6.5
13-Oct to 19-Oct	3.5	2.3	376.1	106	19.9	-9.5	4.9	-0.3
20-Oct to 26-Oct	5.7	3.7	381.8	107	13.5	-8.3	1.6	-1.7
27-Oct to 31-Oct	0.2	1.1	382.0	106	13.8	-5.8	2.5	1.2

* totals were based on period from November 1, 1996 to April 6, 1997.

Table 7.3.6 Weekly weather data for Vegreville 1997.

	Precipitation (mm)				Temperature (Degrees Celsius)			
	Weekly Period		Since April 1st					
Time Period	Total	Normal	Total	% Normal	Max	Min	Mean	From Normal
31-Mar to 06-Apr	0.6	2.9	50.9*	67*	5.8	-19.5	-5.0	-4.1
07-Apr to 13-Apr	0.0	4.4	0.6	8	9.2	-18.2	-6.7	-8.5
14-Apr to 20-Apr	4.7	3.8	5.3	50	16.3	-3.9	5.3	1.4
21-Apr to 27-Apr	26.5	3.6	31.8	225	15.1	-2.2	5.2	-1.0
28-Apr to 04-May	3.6	6.5	35.4	171	16.3	-3.3	5.1	-2.3
05-May to 11-May	1.8	5.5	37.2	142	20.2	-0.7	9.0	0.2
12-May to 18-May	8.8	11.9	46.0	121	25.5	-0.4	11.8	1.9
19-May to 25-May	31.0	8.8	77.0	165	13.4	-1.4	6.0	-5.8
26-May to 01-Jun	14.8	8.4	91.8	166	25.8	6.0	15.0	2.2
02-Jun to 08-Jun	6.4	15.9	98.2	138	23.1	5.4	15.6	1.8
09-Jun to 15-Jun	34.6	15.1	132.8	154	25.5	4.5	17.3	3.4
16-Jun to 22-Jun	53.6	15.9	186.4	183	24.1	7.3	14.0	-0.8
23-Jun to 29-Jun	14.6	24.3	201.0	159	23.9	2.0	12.7	-2.4
30-Jun to 06-Jul	2.2	20.6	203.2	138	23.6	5.0	14.5	-1.3
07-Jul to 13-Jul	6.6	22.4	209.8	124	24.0	6.6	15.2	-1.1
14-Jul to 20-Jul	20.0	20.0	229.8	121	25.7	7.2	17.1	1.0
21-Jul to 27-Jul	7.6	15.9	237.4	116	27.7	5.6	15.9	-0.5
28-Jul to 03-Aug	2.2	14.6	239.6	109	30.5	5.8	18.2	1.5
04-Aug to 10-Aug	0.8	16.7	240.4	102	32.6	4.8	17.8	1.2
11-Aug to 17-Aug	24.6	11.9	265.0	107	26.5	5.7	14.5	-0.9
18-Aug to 24-Aug	10.2	10.4	275.2	106	28.3	2.6	15.4	0.8
25-Aug to 31-Aug	10.6	14.6	285.8	104	26.6	3.7	15.2	1.8
01-Sep to 07-Sep	32.2	14.9	318.0	110	28.4	1.4	14.7	2.7
08-Sep to 14-Sep	2.3	7.9	320.3	108	26.5	-2.2	11.3	1.1
15-Sep to 21-Sep	14.9	10.0	335.2	109	22.7	-2.9	7.8	-1.4
22-Sep to 28-Sep	0.4	5.1	335.6	108	26.8	2.9	14.1	6.0
29-Sep to 05-Oct	2.0	4.7	337.6	107	21.3	-3.5	7.7	0.5
06-Oct to 12-Oct	2.0	2.8	339.6	106	13.0	-5.5	1.2	-5.0
13-Oct to 19-Oct	4.2	3.2	343.8	107	20.1	-8.8	4.6	0.1
20-Oct to 26-Oct	14.0	3.8	357.8	110	12.1	-11.4	0.0	-2.5
27-Oct to 31-Oct	0.8	1.2	358.6	110	11.3	-5.8	2.1	1.9

* totals were based on period from November 1, 1996 to April 6, 1997.

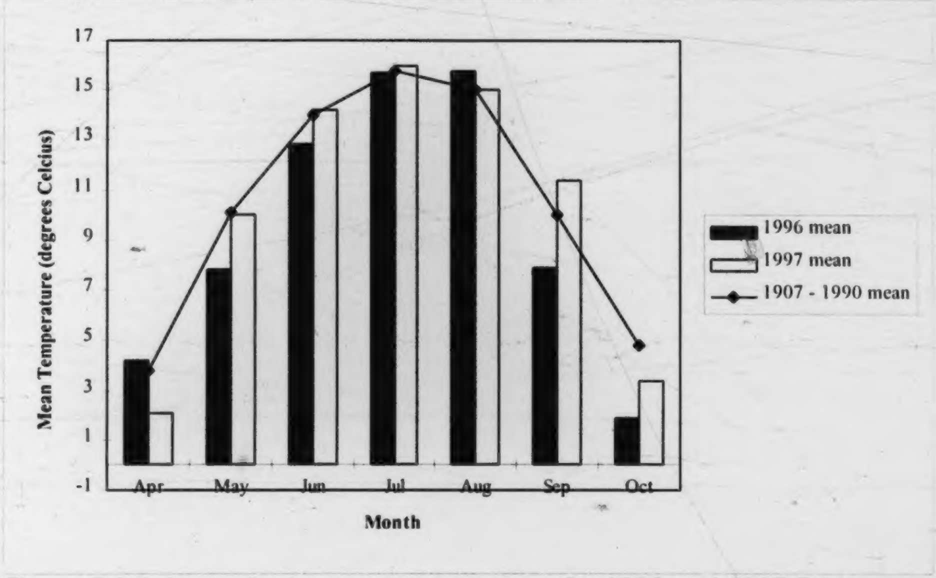

Figure 7.3.1 Lacombe temperature averages for 1996 and 1997 field season and 40 year (plus) averages.

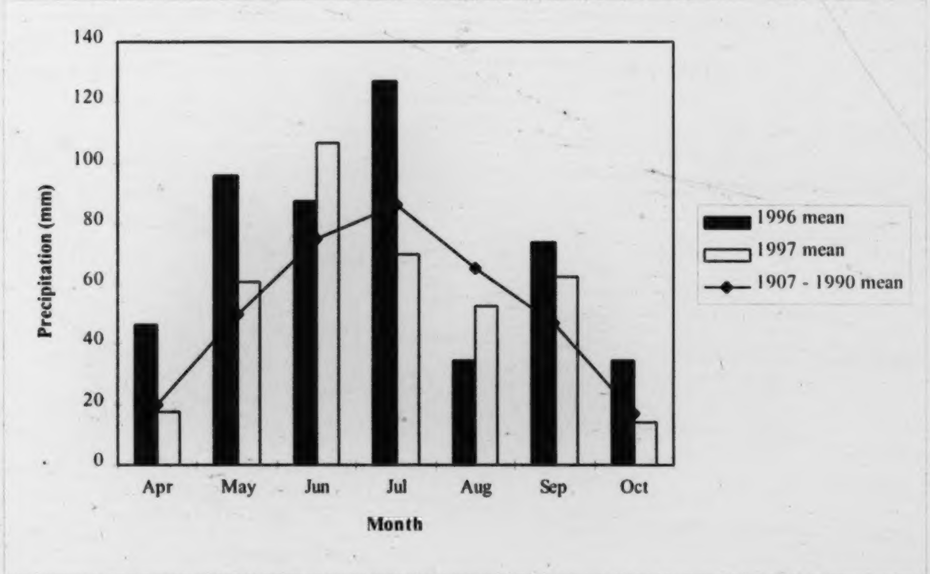

Figure 7.3.2 Lacombe precipitation averages for 1996 and 1997 field season and 40 year (plus) averages.

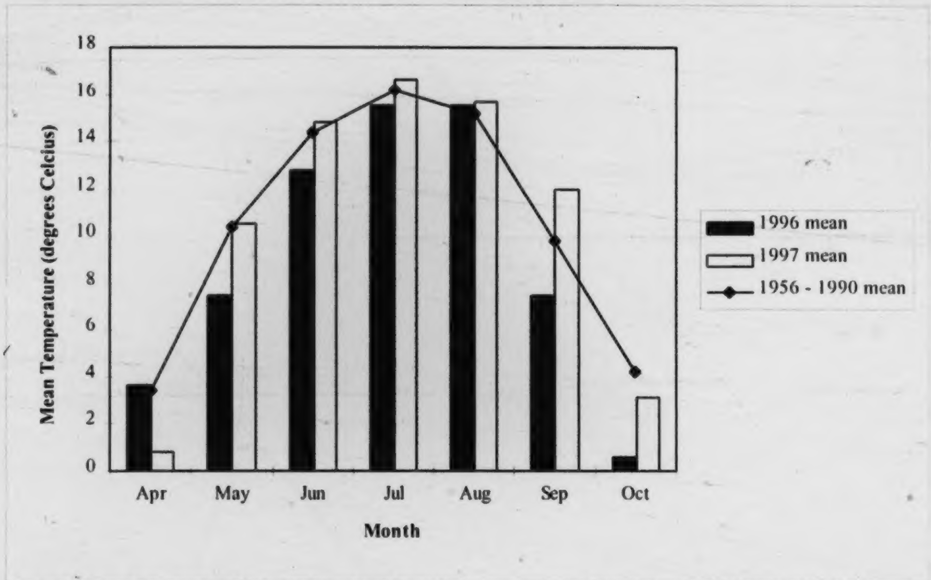

Figure 7.3.3 Vegreville temperature averages for 1996 and 1997 field season and 40 year (plus) averages.

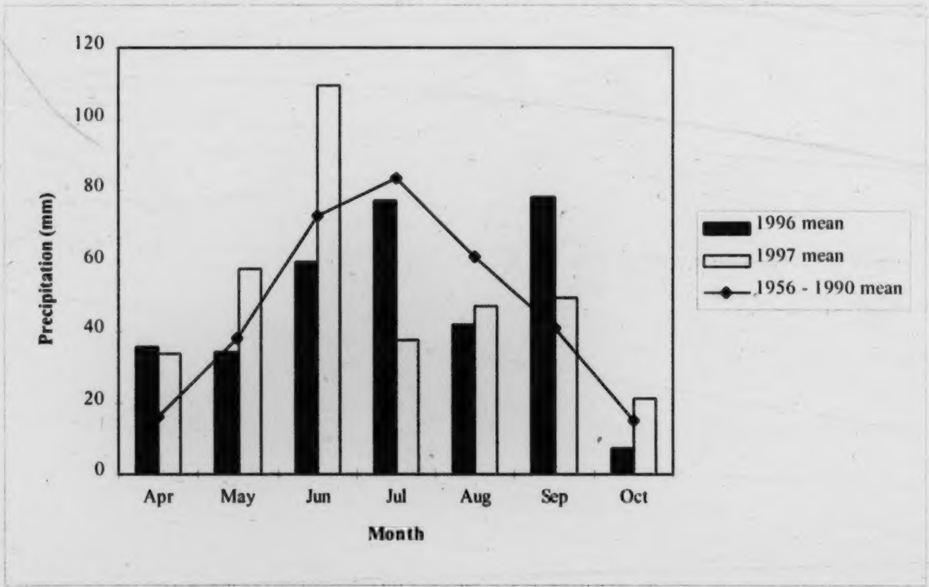

Figure 7.3.4 Vegreville temperature averages for 1996 and 1997 field season and 40 year (plus) averages.

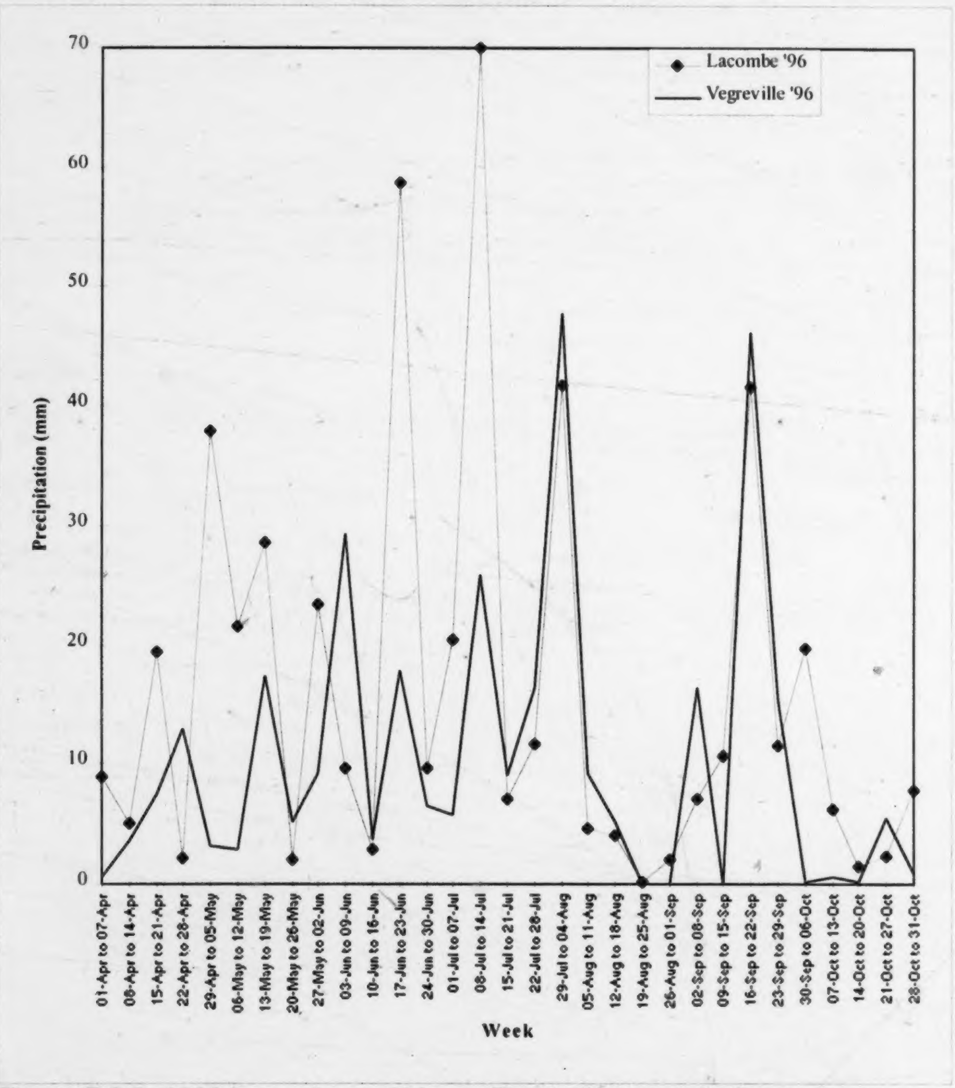

Figure 7.3.5 1996 Lacombe and Vegreville weekly precipitation averages.

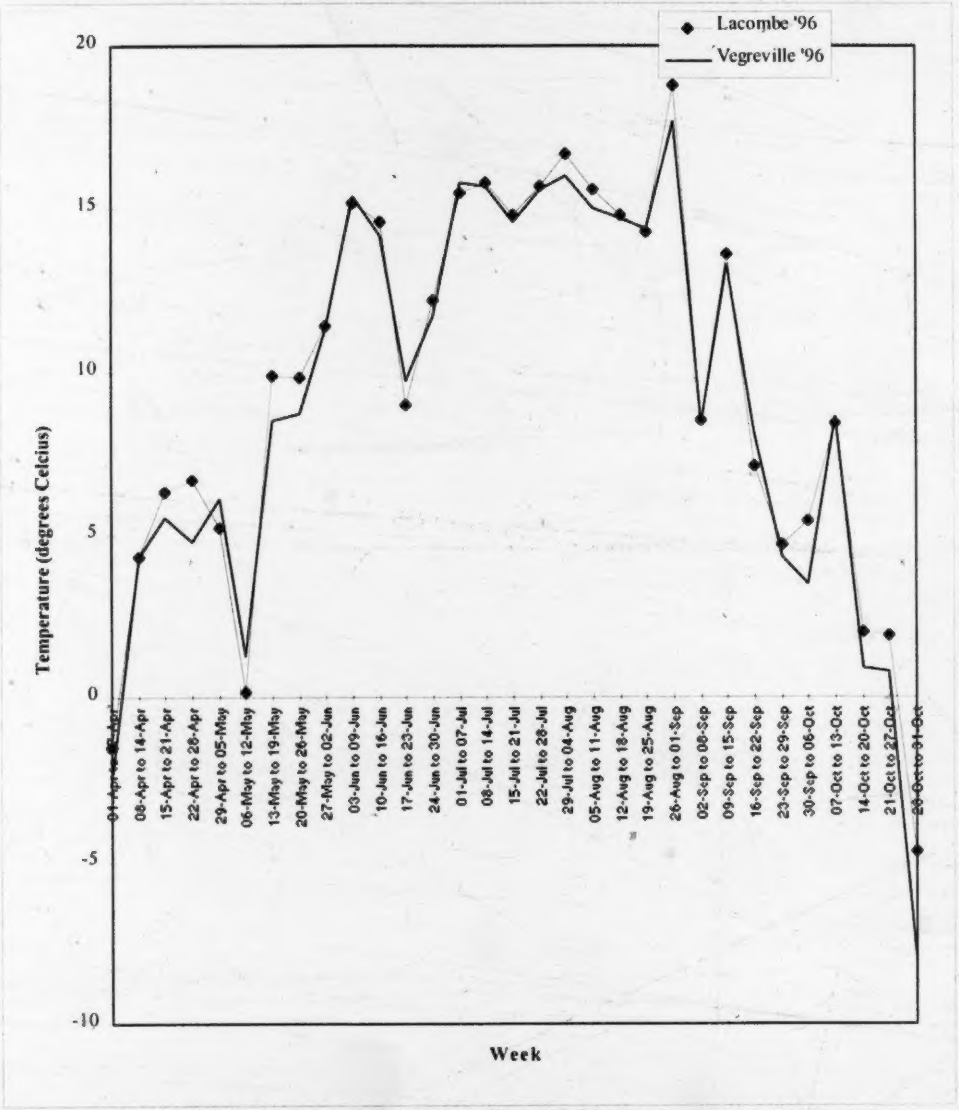

Figure 7.3.6 1996 Lacombe and Vegreville weekly temperature averages.

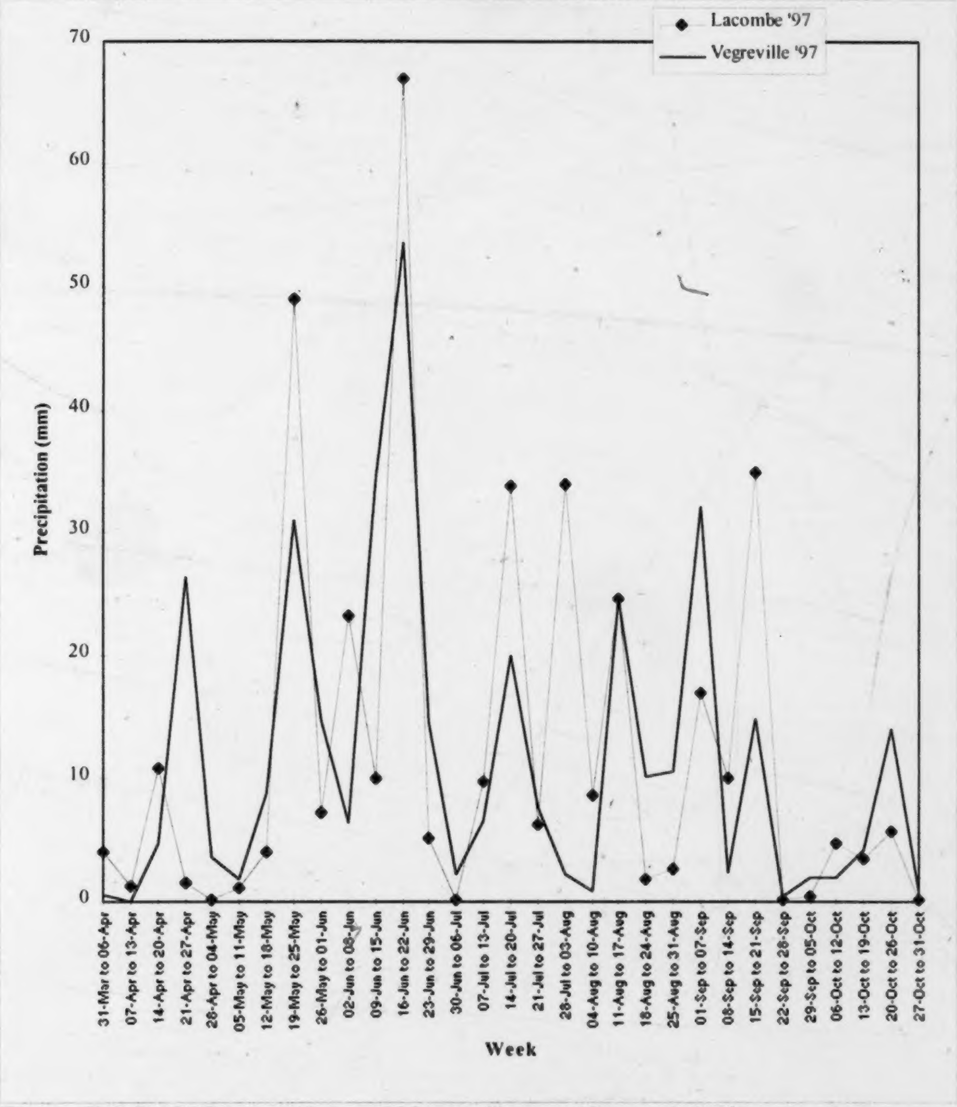

Figure 7.3.7 1997 Lacombe and Vegreville weekly precipitation averages.

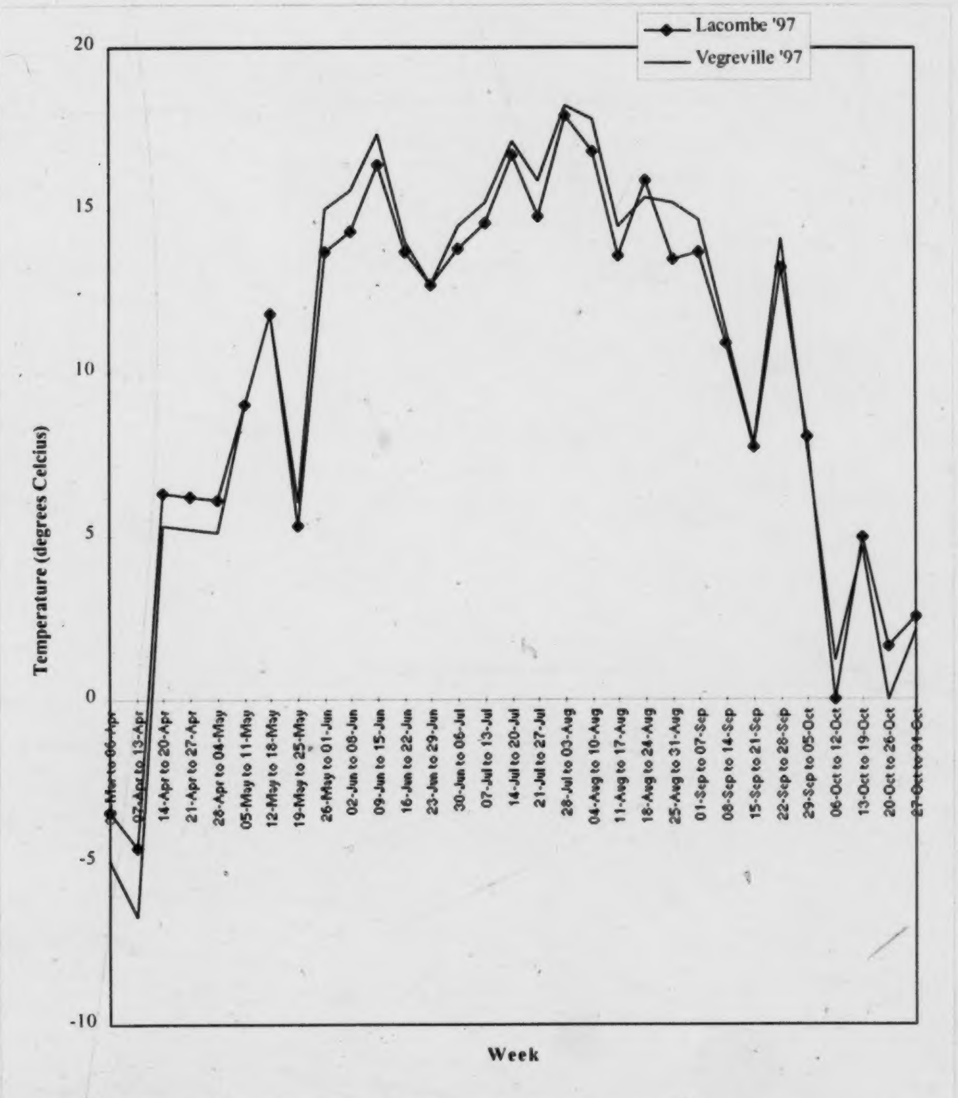

Figure 7.3.8 1997 Lacombe and Vegreville weekly temperature averages.

7.4 Appendices for Greenhouse Competition Experiments

Table 7.4.1 Pressure plate summary data for soil-less medium used in greenhouse experiments.

	% Moisture at Various Pressures			
Sample #	**15.0 Bar**	**1.0 Bar**	**0.33 Bar**	**0.10 Bar**
Sample #1	38.87	51.40	56.71	67.24
Sample #2	39.87	47.72	62.93	70.16
Average %	**39.37**	**49.56**	**59.82**	**68.70**

Table 7.4.2 Canola leaf staging and red root pigweed leaf staging for the greenhouse time of red root pigweed removal experiment.

			Leaf Stage	
Date	**Moisture**	**Weed Density**	**Canola**	**R. R. P.***
Feb. 14	**FC**	**high**	3	2-4
(early weed	**FC**	**low**	3	2-4
removal)	**1/4 FC**	**high**	3	2-4
	1/4 FC	**low**	3	2-4
Feb. 26	**FC**	**high**	6 -bud	6-10
(late weed	**FC**	**low**	6 - bud	6-10
removal)	**1/4 FC**	**high**	6 - bud	6-10
	1/4 FC	**low**	6 - bud	6-10

* Red root pigweed (R.R.P.) leaf area was not taken because leaves were too small.

Table 7.4.3 Canola leaf staging and wild oat leaf staging and leaf area for the greenhouse time of weed removal experiment.

			Leaf Stage		**Wild Oat Leaf Area (cm^2)**	
Date	**Moisture**	**Weed Density**	**Canola**	**Wild Oat**	**Total leaf area**	**Mean leaf area**
March 28	**FC**	**high**	3	5	439	27
(early	**FC**	**low**	3	6	143	36
weed	**1/4 FC**	**high**	3	4	295	18
removal)	**1/4 FC**	**low**	3	5	115	29
April 4	**FC**	**high**	5 - bud	8	1309	82
(late	**FC**	**low**	5 - bud	13	584	146
weed	**1/4 FC**	**high**	4 - bud	7	875	55
removal)	**1/4 FC**	**low**	5 -bud	9	363	91

Table 7.4.4 Summary of means for time of weed removal main effect from red root pigweed greenhouse competition trial. Means were averaged over high and low red root pigweed densities and 1/4 field capacity and field capacity moisture regimes.

	Time of Weed Removal			**Std. Err.**	**Prob.**
	Control	**Early Removal**	**Late Removal**		
Leaf area (cm^2)	211	198	192	**7.0**	**0.16**
Leaf Number	6.14	6.00	6.02	**0.0855**	**0.42**
Leaf wt. (g)	0.529	0.511	0.475	**0.0208**	**0.19**
Stem wt. (g)	0.283	0.265	0.296	**0.0099**	**0.10**
Shoot wt. (g)	0.812	0.776	0.771	**0.0274**	**0.52**
Leaf wt. ratio (g/g)	0.647	0.655	0.614	**0.0077**	**0.002**

Table 7.4.5 Summary of means for moisture regime main effect from red root pigweed greenhouse competition trial. Means were averaged over pre-emergent weed removal, early and late times of weed removal and high and low red root pigweed densities.

	Moisture Regime		**Std. Err.**	**Prob.**
	1/4 Field Capacity	**Field Capacity**		
Leaf area (cm^2)	169	232	**5.6**	**0.0001**
Leaf Number	5.96	6.15	**0.069**	**0.066**
Leaf wt. (g)	0.425	0.585	**0.017**	**0.0001**
Stem wt. (g)	0.259	0.303	**0.0080**	**0.0001**
Shoot wt. (g)	0.684	0.889	**0.022**	**0.0001**
Leaf wt. ratio (g/g)	0.623	0.655	**0.0063**	**0.0009**

Table 7.4.6 Summary of means for time of weed removal by moisture regime interaction from red root pigweed greenhouse competition trial. Means were averaged over high and low red root pigweed weed densities.

	Time of Weed Removal						**Std. Err.**	**Prob.**
	Control		**Early Removal**		**Late Removal**			
Moisture	**1/4 FC**	**FC**	**1/4 FC**	**FC**	**1/4 FC**	**FC**		
Leaf area (cm^2)	177	245	163	234	167	216	**10.0**	**0.50**
Leaf Number	6.14	6.15	5.85	6.14	5.89	6.15	**0.121**	**0.47**
Leaf wt. (g)	0.443	0.615	0.411	0.610	0.421	0.529	**0.0295**	**0.30**
Stem wt. (g)	0.266	0.299	0.233	0.296	0.277	0.314	**0.0139**	**0.50**
Shoot wt. (g)	0.709	0.915	0.645	0.907	0.699	0.844	**0.0388**	**0.33**
Leaf wt. ratio (g/g)	0.625	0.670	0.639	0.671	0.604	0.625	**0.0101**	**0.54**

Table 7.4.7 Summary of means for red root pigweed density main effect from red root pigweed greenhouse competition trial. Means were averaged over pre-emergent, early and late times of weed removal and 1/4 field capacity and field capacity moisture regimes.

	Weed Density		**Std. Err.**	**Prob.**
	High	**Low**		
Leaf area (cm^2)	200	201	**5.8**	**0.86**
Leaf Number	6.02	6.09	**0.069**	**0.46**
Leaf wt. (g)	0.514	0.496	**0.0170**	**0.46**
Stem wt. (g)	0.281	0.281	**0.0080**	**0.95**
Shoot wt. (g)	0.795	0.778	**0.022**	**0.59**
Leaf wt. ratio (g/g)	0.643	0.635	**0.0063**	**0.37**

Table 7.4.8 Summary of means for time of weed removal by weed density interaction from red root pigweed greenhouse competition trial. Means were averaged over 1/4 field capacity and field capacity moisture regimes.

	Time of Weed Removal						**Std. Err.**	**Prob.**
	Control		**Early Removal**		**Late Removal**			
Weed Density	**High**	**Low**	**High**	**Low**	**High**	**Low**		
Leaf area (cm^2)	210	212	200	197	189	194	**10.0**	**0.93**
Leaf Number	6.01	6.28	6.10	5.89	5.93	6.10	**0.121**	**0.12**
Leaf wt. (g)	0.537	0.520	0.522	0.500	0.482	0.468	**0.0295**	**0.99**
Stem wt. (g)	0.267	0.298	0.271	0.258	0.303	0.288	**0.310**	**0.18**
Shoot wt. (g)	0.805	0.819	0.794	0.758	0.786	0.757	**0.0388**	**0.78**
Leaf wt. ratio (g/g)	0.662	0.632	0.654	0.656	0.612	0.617	**0.0101**	**0.24**

Table 7.4.9 Summary of means for moisture regime by red root pigweed density interaction for red root pigweed greenhouse competition trial. Means were averaged over two weed densities and two moisture regimes.

	Moisture Regimes				**Std. Err.**	**Prob.**
	1/4 FC		**FC**			
Weed Density	**High**	**Low**	**High**	**Low**		
Leaf area (cm^2)	167	171	233	231	**8.2**	**0.71**
Leaf Number	5.86	6.06	6.17	6.12	**0.0988**	**0.21**
Leaf wt. (g)	0.425	0.425	0.603	0.567	**0.0241**	**0.46**
Stem wt. (g)	0.255	0.263	0.307	0.300	**0.0114**	**0.50**
Shoot wt. (g)	0.680	0.688	0.910	0.867	**0.0317**	**0.42**
Leaf wt. ratio (g/g)	0.626	0.619	0.660	0.651	**0.0089**	**0.95**

Table 7.4.10 Summary of means for time of weed removal main effect from wild oat greenhouse competition trial. Means were averaged over high and low wild oat densities and 1/4 field capacity and field capacity moisture regimes.

	Time of Weed Removal			**Std. Err.**	**Prob.**
	Control	**Early Removal**	**Late Removal**		
Leaf area (cm^2)	173	137	107	**3.9**	**0.0001**
Leaf Number	5.039	4.86	4.48	**0.051**	**0.0001**
Leaf wt. (g)	0.447	0.360	0.279	**0.00949**	**0.0001**
Stem wt. (g)	0.303	0.226	0.216	**0.0108**	**0.0001**
Plant wt. (g)	0.750	0.587	0.495	**0.0170**	**0.0001**
leaf wt. ratio (g/g)	0.607	0.622	0.559	**0.0072**	**0.0001**

Table 7.4.11 Summary of means for moisture regime main effect from wild oat greenhouse competition trial. Means were averaged over pre-emergent weed removal, early and late times of weed removal and high and low wild oat densities.

	Moisture Regime		**Std. Err.**	**Prob.**
	1/4 Field Capacity	**Field Capacity**		
Leaf area (cm^2)	124	154	**3.2**	**0.0001**
Leaf Number	4.77	4.81	**0.0416**	**0.48**
Leaf wt. (g)	0.330	0.395	**0.00774**	**0.0001**
Stem wt. (g)	0.190	0.306	**0.00883**	**0.0001**
Shoot wt. (g)	0.520	0.701	**0.0138**	**0.0001**
Leaf wt. ratio (g/g)	0.630	0.562	**0.0059**	**0.0001**

Table 7.4.12 Summary of means for time of weed removal by moisture regime interaction from wild oat greenhouse competition trial. Means were averaged over high and low wild oat weed densities.

	Time of Weed Removal						**Std. Err.**	**Prob.**
	Control		**Early Removal**		**Late Removal**			
Moisture	**1/4 FC**	**FC**	**1/4 FC**	**FC**	**1/4 FC**	**FC**		
Leaf area (cm^2)	151	196	121	154	101	114	**5.3**	**0.02**
Leaf Number	4.95	5.12	4.87	4.85	4.50	4.46	**0.072**	**0.30**
Leaf wt. (g)	0.398	0.496	0.321	0.400	0.271	0.287	**0.013**	**0.01**
Stem wt. (g)	0.218	0.387	0.175	0.277	0.177	0.255	**0.015**	**0.01**
Shoot wt. (g)	0.616	0.884	0.496	0.677	0.448	0.543	**0.024**	**0.004**
Leaf wt. ratio (g/g)	0.648	0.567	0.650	0.595	0.593	0.525	**0.010**	**0.44**

Table 7.4.13 Summary of means for wild oat density main effect from wild oat greenhouse competition trial. Means were averaged over pre-emergent, early and late times of weed removal and 1/4 field capacity and field capacity moisture regimes.

	Weed Density		**Std. Err.**	**Prob.**
	High	**Low**		
Leaf area (cm^2)	117	161	**3.1**	**0.0001**
Leaf Number	4.61	4.97	**0.0416**	**0.0001**
Leaf wt. (g)	0.303	0.421	**0.00774**	**0.0001**
Stem wt. (g)	0.210	0.0286	**0.00883**	**0.0001**
Shoot wt. (g)	0.514	0.707	**0.0139**	**0.0001**
Leaf wt. ratio (g/g)	0.589	0.604	**0.0059**	**0.075**

Table 7.4.14 Summary of means for time of weed removal by weed density interaction from wild oat greenhouse competition trial. Means were averaged over 1/4 field capacity and field capacity moisture regimes.

	Time of Weed Removal						**Std. Err.**	**Prob.**
	Control		**Early Removal**		**Late Removal**			
Weed Density	**High**	**Low**	**High**	**Low**	**High**	**Low**		
Leaf area (cm^2)	162	185	118	157	72	143	**5.3**	**0.0006**
Leaf Number	4.89	5.187	4.78	4.95	4.17	4.79	**0.0722**	**0.010**
Leaf wt. (g)	0.422	0.472	0.307	0.413	0.181	0.377	**0.0134**	**0.0001**
Stem wt. (g)	0.281	0.324	0.186	0.265	0.163	0.269	**0.0153**	**0.13**
Shoot wt. (g)	0.703	0.797	0.494	0.679	0.344	0.647	**0.0240**	**0.0006**
Leaf wt. ratio (g/g)	0.609	0.605	0.628	0.617	0.529	0.590	**0.0102**	**0.002**

Table 7.4.15 Summary of means for moisture regime by red root pigweed density interaction for wild oat greenhouse competition trial. Means were averaged over two weed densities and two moisture regimes.

	Moisture Regime				**Std. Err.**	**Prob.**
	1/4 FC		**FC**			
Weed density	**High**	**Low**	**High**	**Low**		
Leaf area (cm^2)	105.0	144.0	129.0	179.0	**4.5**	**0.2265**
Leaf Number	4.583	4.969	4.646	4.990	**0.05895**	**0.7260**
Leaf wt. (g)	0.2812	0.3792	0.3265	0.4635	**0.01096**	**0.0846**
Stem wt. (g)	0.1647	0.2162	0.2563	0.3570	**0.01250**	**0.0572**
Shoot wt. (g)	0.4459	0.5954	0.5828	0.8205	**0.01965**	**0.0315**
Leaf wt. ratio (g/g)	0.6234	0.6383	0.5546	0.5706	**0.00839**	**0.9467**

7.5 Appendices for Greenhouse Glyphosate Application Experiment

Table 7.5.1 Summary of means for canola growth parameters from the glyphosate application trial. Treatments represent canola growth stage regarding glyphosate application: treatment 1 = 1 to 2 leaf stage of canola, treatment 2 = 3 to 4 leaf stage of canola, treatment 3 = 5 to 6 leaf stage of canola, treatment 4 = treatments 1 and 2, treatment 5 = treatments 1 and 3, treatment 6 = treatments 2 and 3, treatment 7 = treatments 1, 2, and 3, and treatment 8 = no glyphosate (control).

	Variable Measured					
Treatment	**Leaf Area (cm^2)**	**Leaf wt. (g)**	**Stem wt. (g)**	**Shoot wt. (g)**	**Specific leaf wt. (g/cm^2)**	**Leaf wt. Ratio (g/g)**
1	294	0.775	0.420	1.195	0.00264	0.664
2	298	0.793	0.454	1.247	0.00269	0.656
3	315	0.873	0.495	1.368	0.00278	0.659
4	235	0.589	0.325	0.914	0.00258	0.669
5	239	0.624	0.324	0.947	0.00258	0.675
6	265	0.719	0.349	1.069	0.00271	0.679
7	198	0.538	0.287	0.825	0.00273	0.671
8	327	0.868	0.613	1.482	0.00269	0.610
Std. Error	18.5	0.053	0.050	0.087	0.000071	0.021